Implementing the cost-optimal methodology in EU countries

Lessons learned from three case studies

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LESSONS LEARNED FROM THREE CASE STUDIES

BPIE

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1. INTRODUCTION AND RATIONALE

Across Europe, buildings are responsible for the largest share of energy consumption and associated greenhouse gas (CO_2) emissions and therefore they are a key sector to reach the long term climate and energy targets.

The building sector has a significant cost-effective energy and CO_2 emissions savings potential, which should be properly addressed by policies in order to mobilise the market towards a low carbon society and trigger multiple benefits (such as the independence from energy imports from politically unstable areas, job creation, improved air quality and indoor comfort, reduced fuel poverty etc.)

In summary, the building sector is key to achieving the EU's energy, climate and resource efficiency long-term strategies:

- To reach the long-term decarbonisation goals, the *EU Roadmap for moving to a competitive low carbon economy in 2050* (COM, 2011a) identified potential CO_2 emissions reduction of 88% to 91% by 2050 compared to 1990 levels, related to the residential and services sectors.
- In addition, the *Energy Roadmap 2050* (COM, 2011b) considers that the high "energy efficiency potential in new and existing buildings is key" to reach a sustainable energy future in the EU, contributing significantly to the reduction of energy demand, the security of energy supply and the increase of competitiveness.
- Furthermore, the *Roadmap to a Resource Efficient Europe* (COM, 2011c) identifies buildings among the three key sectors responsible for 70% to 80% of all environmental impacts. Therefore, better construction and use of buildings in the EU would influence 42% of the final energy consumption, about 35% of the CO_2 emissions, more than 50% of all extracted materials and could save up to 30% of water consumption.

However, to unleash the full potential of energy savings related to buildings, the additional value of improved energy efficiency (e.g. improved indoor climate, reduced energy cost, improved property value, etc.) must be recognised, and the lifetime costs of buildings have to be considered rather than just focusing on investment costs. Over the last decade, building policies in the European Union increased in their scope and coverage and are moving towards an integrated approach taking into account the energy, environmental, financial and comfort related aspects.

The recast Energy Performance of Buildings Directive (EPBD, 2010/31/EU) stands as an important milestone for building policies, requiring all European Member States to:

a) Introduce minimum energy performance requirements for buildings, building elements and technical building systems,

b) Set these requirements based on a cost-optimal methodology taking into account the lifetime costs of the building, and

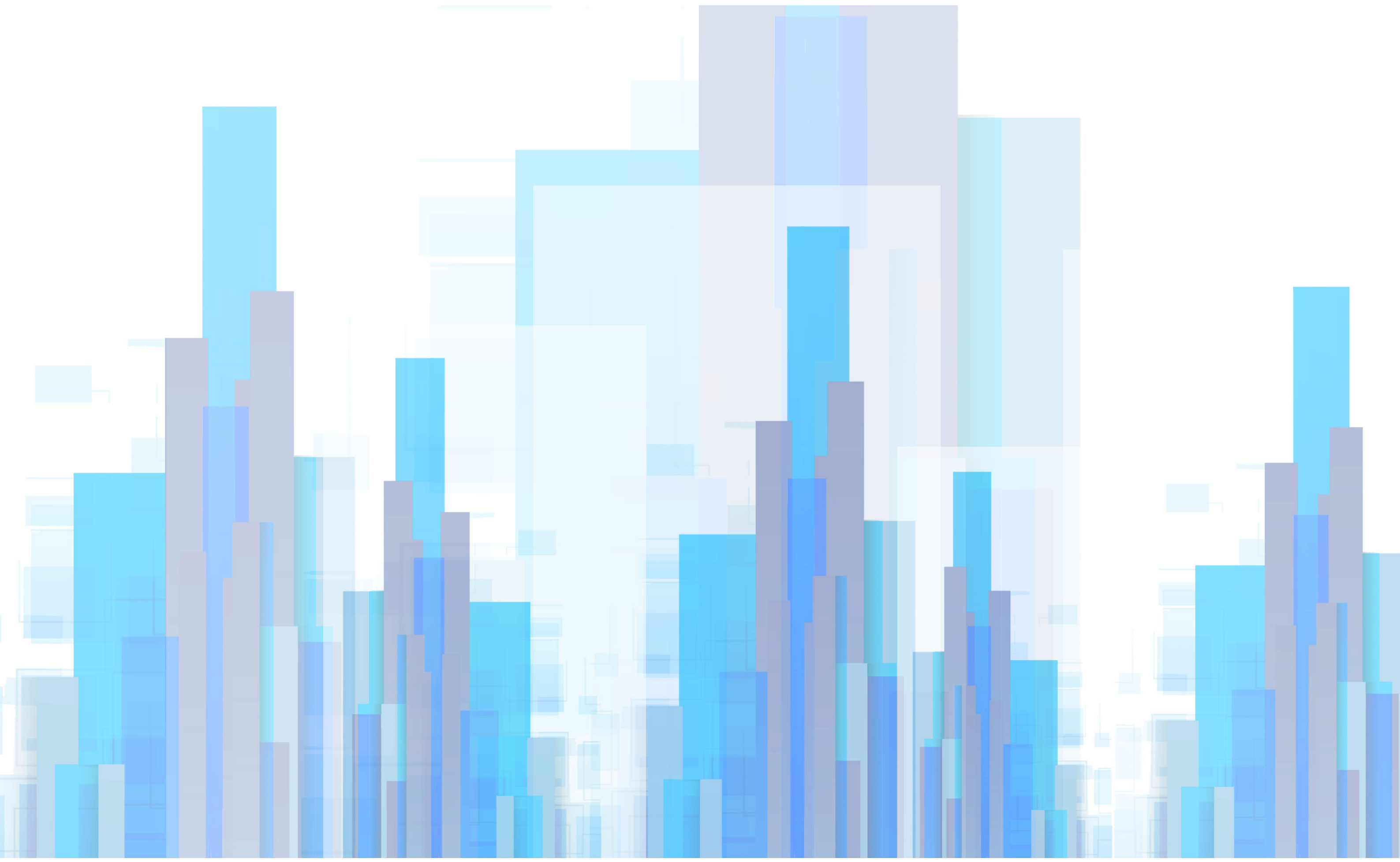
c) Construct only nearly Zero-Energy Buildings from 2020 onwards.

The cost-optimal methodology introduces - for the very first time - the prerequisite to consider the global lifetime costs of buildings to shape their future energy performance requirements. Thus, the evaluation of buildings' requirements will not anymore be related only to the investment costs, but will additionally take into account the operational, maintenance, disposal and energy saving costs of buildings.

The Commission Cost-Optimality Delegated Regulation (COM, 2012a) establishes a comparative framework methodology to determine a cost-optimal level of minimum energy performance of buildings and building elements. A guidance document (COM, 2012b) on how to implement the methodology at national level was published by the EU Commission in April 2012.

However, EU regulation and guidelines provide to Member States a very large degree of flexibility when selecting the input data for the calculation. Flexibility is also provided for the selection of reference buildings, optional discount rate (freedom to choose if requirements shall be based on a societal or a private economic calculation), energy cost, equipment and packages, maintenance and labour costs, primary energy factors and estimated economic lifecycle.

Convinced that Member States would benefit from additional guidance on the cost-optimality process and on how to use the methodology relating to nearly Zero-Energy Buildings (nZEB) requirements and long-term climate goals, BPIE intends to provide additional practical examples. The goal is to evaluate the implications of different critical parameters, as well as to share the good practices across EU countries.



2. AIMS AND METHODOLOGY

As mentioned previously, the EPBD asks Member States to implement a cost-optimal methodology to benchmark minimum requirements for the energy performance of buildings and building elements. Nevertheless, making the calculations for the cost-optimal analysis is a big challenge.

This study presents three cost-optimal calculations. The overall aim is to provide a deeper analysis and to provide additional guidance on how to properly implement the cost-optimality methodology in Member States.

Without proper guidance and lessons from exemplary case studies using realistic input data (reflecting the likely future development), there is a risk that the cost-optimal methodology may be implemented at sub-optimal levels. This could lead to a misalignment between the defined cost-optimal levels and the long-term goals, leaving a significant energy saving potential unexploited. Therefore, this study provides more evidence on the implementation of the cost-optimal methodology and highlights the implications of choosing different values for key factors (e.g. discount rates, simulation variants/packages, costs, energy prices) at national levels.

The study demonstrates how existing national nZEB definitions can be tested for cost-optimality and explores additional implications of the EU decarbonisation and resource efficiency goals. Thus, the study will ultimately contribute to prompt the transition towards the implementation of nZEB by 2020.

Based on real data, the study validates the benefits to have a proper and rigorous implementation of the cost-optimal methodology at national level. It serves to:

- Document the benefits of a proper implementation of the cost-optimal methodology;
- Check the implication of ambitious variants and packages towards nearly zero-energy levels following the cost-optimal approach;
- Check/document how to properly perform the financial and economic analysis of the selected variants/packages;
- Analyse the impact of choosing different discount rates, energy price development scenarios and potential options in implementing the cost-optimal methodology at national levels;
- Provide additional knowledge-based and technology neutral support to the European Commission and Concerted Action EPBD in their efforts to achieve a proper implementation of the *Cost-Optimal Delegated Regulation* (EC, 2012a) across the European Union.

All findings and recommendations in this study are based on three country reports providing concrete examples for Austria, Germany and Poland.

The practical cost-optimal evaluation was performed for new residential buildings and was based on the recommended approach and indication of the Commission guidelines and, wherever possible, on national requirements in the countries selected.

3. BRIEF PRESENTATION OF THE EPBD COST-OPTIMALITY

According to the EPBD recast, Member States (MS) must "assure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels." MS must also "take the necessary measures to ensure that minimum energy performance requirements are set for building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are replaced or retrofitted, with a view to achieving cost-optimal levels" (EPBD Art. 4.1 and also in Recital 14).

The cost-optimal level is defined as "the energy performance level which leads to the lowest cost during the estimated economic lifecycle." MS will determine this level by taking into account a range of costs including investments, maintenance, operating costs and energy savings. The economic lifecycle is defined in the *Cost-Optimal Delegated Regulation* of the Commission (EC, 2012a).

The EPBD requires MS to report on the comparison between their minimum energy performance requirements and the calculated cost-optimal levels using the comparative methodology framework provided by the Commission (EPBD Arts. 5.2, 5.3, 5.4 and Annex III). The discrepancy between the calculated cost-optimal level of national minimum energy performance requirements and the minimum energy performance requirements in force should not exceed 15 % (EPBD recital 14).

The relevant legal document providing the frame is the Commission's *Cost-Optimal Delegated Regulation* (EC, 2012a). To support MS, this regulation is accompanied by *Guidelines* (EC, 2012b) outlining how to apply the framework to calculate the cost-optimal performance level. The cost-optimal methodology should be based on dedicated European CEN standards developed to support the EPBD implementation.

The comparative methodology framework requires MS to:

- Define reference buildings that are characterized by and representative of their functionality and climate conditions. The reference buildings must cover residential and non-residential buildings, both new and existing ones;
- Define energy efficiency measures that are assessed for the reference buildings. These may be measures for buildings as a whole, for building elements or for a combination of building elements;
- Assess the final and primary energy need of the reference buildings by calculating the impact of different packages of measures, and
- Calculate the costs (i.e. the net present value) of the energy efficiency measures during the expected economic life cycle applied to the reference buildings, taking into account investment costs, maintenance and operating costs, as well as earnings from produced energy.

MS are requested to report to the Commission all input data and assumptions used for these calculations as well as the results of the calculations from two perspectives: the macroeconomic level (societal level) or the financial level (private investor). Member States can then choose which one to apply at the national level.

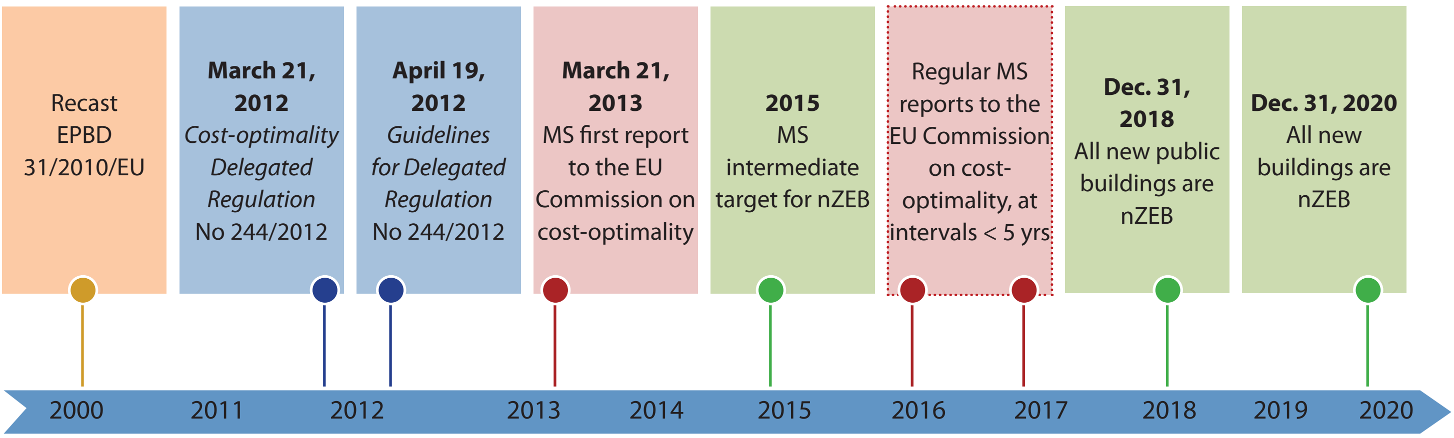
In the event that the cost-optimal comparative analysis shows that the national requirements in force are much less ambitious than the cost-optimal level (i.e. if the energy requirements in force are more than 15% above the cost-optimal level), MS need to justify this gap to the Commission. If the gap cannot be justified, a plan should be developed to outline steps on how to reduce the gap significantly. In that case, the Commission will publish a report on the progress of MS.

IMPLEMENTATION TIMELINE

- A proposal for the framework was adopted by the European Commission on January 16, 2012.
- The Council voted on March 1, 2012. There were no objections.
- The framework was announced, and thus legally binding, on March 21, 2012.
- The *Guidelines* (EC, 2012b) were published on April 19, 2012.

MS must report their level of energy requirements to the Commission at regular intervals of maximum five years, with the first report due by March 21, 2013, one year after the announcement.

Figure 1: Implementation timeline for cost-optimality and nearly Zero-Energy Buildings' requirements of EPBD

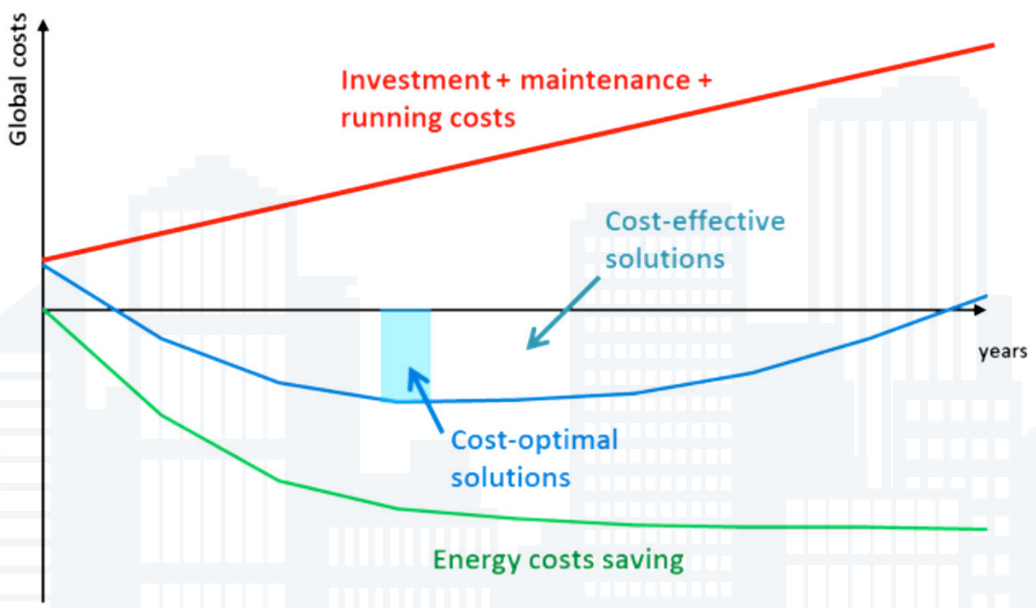


4. GENERAL GUIDANCE ON IMPLEMENTING THE COST-OPTIMALITY REQUIREMENT

The concepts of cost-effectiveness and cost-optimality are related, but still different, the latter being a special case of the first. Both are based on comparing the costs and (priced) savings of a potential action - in this case, of introducing a particular level of minimum energy performance requirements for buildings. In general, a measure or package of measures is cost-effective when the cost of implementation is lower than the value of the benefits that result over the expected life of the measure. Future costs and savings are discounted, with the final result being a "net present value". If the "net present value" is positive (NPV>0), the action is "cost-effective" (for the particular set of assumptions used in the calculation). The action or combinations of actions that maximise the net present value are the "cost-optimal" actions.

Cost-optimality is relatively easy to determine for single measures operating in well-defined conditions (e.g. the optimal insulation thickness for pipework operating at a constant temperature in a constant-temperature environment). However, the process is considerably more difficult for complete buildings, and even more so for combinations of buildings, such as a national building stock.

Figure 2: Relationship between cost-optimality and cost-effectiveness



DERIVATION OF COST-OPTIMAL LEVEL

As a matter of fact, the cost-optimum is rarely found as a single package of measures applied to a reference building, but rather as a set of more or less equally valid or cost-optimal solutions that can be considered as a cost-optimal range. Therefore, for each building type there will be a set or even a 'cloud' of curves, depending on the building and on the combinations of cost-optimal variants used in the cost-optimal evaluation.

Test runs performed for the Commission revealed that the number of calculated variants should certainly not be lower than ten plus the reference case. This will ensure that it is possible to identify a line that represents the cost-curve and thus reveals the optimum.

In identifying the packages, it is important to apply the so-called *Trias Energetica principle*, which is based on the following three-step approach:

1. Reduce the demand for energy by avoiding waste and implementing energy-saving measures;
2. Use sustainable sources of energy like wind, the sun, water and the ground;
3. Use fossil fuel energy as efficiently as possible and only if sustainable sources of energy are unavailable.

COST-CALCULATION PERSPECTIVE

Cost-effectiveness and cost-optimality can be considered from several perspectives, each providing usually a different result. There are two important perspectives:

- At societal level: the macroeconomic perspective,
- At private / end-users level (financial): the microeconomic perspective

Each of these perspectives serves a different purpose and undoubtedly, MS will assign a different importance to each of them when setting requirements.

Macroeconomic calculation levels include costs of CO_2 emissions and exclude taxes and subsidies. MS must determine the discount rate in the macroeconomic calculation after having performed a sensitivity analysis with at least two different rates, one of them should be 3% as specified in the *Cost-Optimality Delegated Regulation*.

MS must carry out both financial and macroeconomic calculations, but they still have the prerogative to decide which perspective will be the final national benchmark.

REFERENCE BUILDINGS

Article 5 of the EPBD (recast) requires MS to establish the comparative methodology framework in accordance with Annex III and to differentiate between different categories of buildings. MS must define reference buildings that are characterised by and representative of their functionality and geographic location, including indoor and outdoor climate conditions. The reference buildings must cover residential and non-residential buildings, both new and existing ones.

MS have to establish at least nine reference buildings – one for new and two for existing buildings, for single-family, multi-family, and office buildings respectively. Annex I includes a list of building categories.

For the purpose of the energy performance calculation, the following buildings should be adequately classified:

- Single-family houses of different types,
- Blocks of flats,
- Offices,
- Educational buildings,
- Hospitals,
- Hotels and restaurants,
- Sports facilities,
- Wholesale and retail trade services buildings,
- Other types of energy-consuming buildings.

Ideally, reference buildings are defined based on the characteristics of the building stock. They are defined for two main purposes:

- To represent the aggregate stock of buildings (current practice as well as new design and construction techniques and technology) affected by regulation;
- And to identify sectors that would be disadvantaged by requirements that might, nevertheless, be cost-optimal overall.

Due to the limited statistical knowledge about the building stock, the choice of reference buildings becomes more arbitrary. This might be a source of deviation and inconsistency in the cost-optimum comparison. In addition, many combinations of different service systems in the reference buildings will result in lots of calculations.

In the past, several EU projects have dealt with this issue, as well as some actual projects, which collect information on existing national reference buildings or try to develop national sets of reference buildings, with IEE TABULA being one of them. TABULA aims at creating a harmonised structure for European building typologies with a focus on residential buildings (www.building-typology.eu).

EXISTING BUILDING STOCK

In addition to energy performance requirements for new buildings, MS must also set cost-optimal levels requirements for the existing building stock.

Many of the energy improvements in the existing building sector will be driven by major renovations. Therefore, it is crucial to communicate information in a proper way, in combination with other planned works and energy improvements, to ensure that cost-optimal levels are achieved each time a renovation takes place.

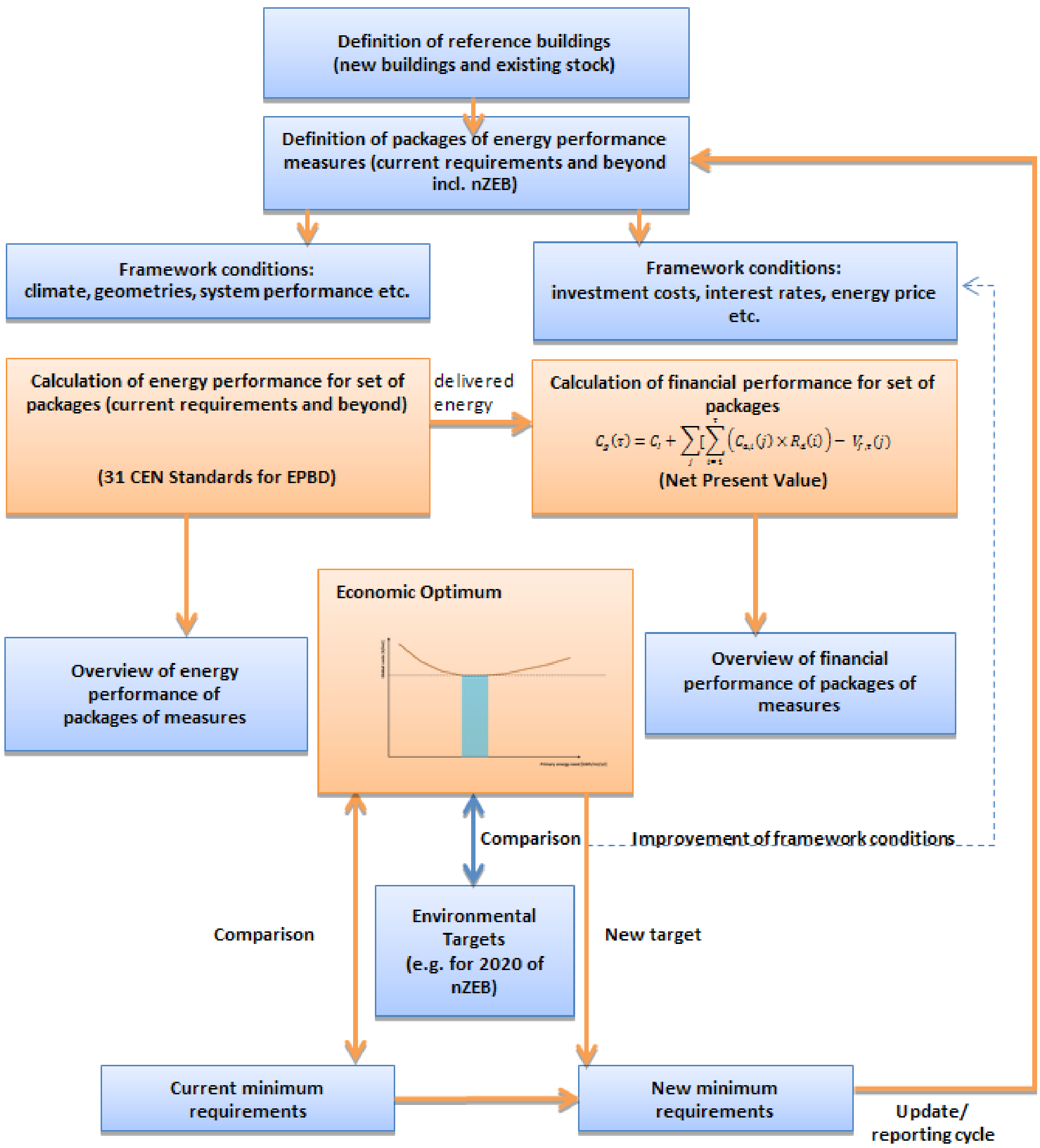
However, there are additional issues that need to be taken into consideration when applying the methodology of cost-optimality on existing buildings:

- The focus is only on costs while in many cases the decision to renovate is also driven by other factors (improved indoor climate, changes in functionality, need for maintenance etc.).
- The split incentive between actors, in case of selling (added property value –positive impact).
- The whole-building or component requirements can result in different solutions with the risk that one optimal solution identified (e.g. on a component level) will be a hindrance for a better (later) solution at whole-building level.

COST-OPTIMALITY IMPLEMENTATION PROCESS

The complete process to assess and report on cost-optimal levels for buildings energy performance is extensively described in several studies (eceee, 2011; BPIE, 2010) as well as in the guidelines document of the Commission. The following diagram (BPIE, 2010) summarizes the necessary steps to be followed when implementing cost-optimality at national level.

Figure 3: Implementation steps of cost-optimal methodology
(Source: BPIE, 2010)



The implementation of cost-optimality starts with the definition of reference buildings and of packages of measures applied to these buildings.

The cost-optimal calculation has to be done by applying a varied combination of packages of measures on reference buildings (starting with the current requirements and beyond, including the nZEB level), in both energy performance and financial performance terms.

The energy performance calculations have to be performed based on national methodologies, which should consider the European standards developed to support the implementation of the EPBD - more guidance is available in CEN/TR 15615:2008 (CEN, 2008). Framework conditions for the calculations have to be defined in terms of climate data, performance of energy systems, etc.

To assess the financial performance of the chosen combinations of packages, the global cost calculation method from the European Standards EN 15459 *(Energy performance of buildings – economic evaluation procedure for energy systems in buildings)* can be used. This method results in a discounted value of all costs for a defined calculation. The calculation of energy costs is thereby fed by the results of the energy performance calculations.

Input data for the calculations are investment, running and disposal costs, discount rates, energy prices and scenarios, lifetime of materials and equipment. A cost curve shows the assessed combinations of energy and financial performance. Thus, an economic optimum can be derived.

The relationship between current requirements and the position of the cost-optimal points has to be repeated and submitted to the Commission periodically (at an interval of no longer than five years) and can be used to update requirements, if appropriate.

The comparison with future nZEB levels and longer-term environmental goals could feed into a new calculation and evaluation process. Although not part of the EPBD requirements, this analysis could be used as a national steering tool enabling the assessment of improved framework conditions and fostering the deployment of more efficient materials, technology and building techniques (e.g. the introduction of soft loans). In that case, implementing the cost-optimality calculation becomes even more beneficial, as the calculation would then not only contribute to the specific evaluation of building codes requirements but also help shape future building policies both from a medium and long-term perspective.

A more detailed guidance on implementing cost-optimality is presented in Annex I.

5. COST-OPTIMALITY, NEARLY ZERO-ENERGY BUILDINGS AND LONG-TERM CLIMATE AND ENERGY GOALS

According to EPBD - Article 9, from 2020 onwards new buildings constructed within the EU have to be at "nearly zero-energy" levels. And from 2013, the *Cost-Optimality Delegated Regulation* setting the energy performance requirements in the MS building codes will have to be applied. For new buildings it is therefore strongly recommended to apply the cost-optimality methodology. It helps to understand and manage the implications of implementing requirements for nearly Zero-Energy Buildings.

Indeed, the nZEB definition for 2020 has to be more ambitious than current cost-optimal levels and aligned to the long term climate and energy goals.

The cost-optimal methodology should take into account the long-term decarbonisation goals of the European Union. If the EU countries want to meet the 2050 goals for CO_2 reduction, then the upcoming nZEB requirements for new buildings have to be nearly Zero-Carbon Buildings (nZCB), with associated emissions below 3kg CO_2/m^2yr[1] (BPIE, 2011). However, in order to fulfil the sustainable building concept, the CO_2 reduction requirement cannot be a target in itself without being associated with energy reduction requirements.

Accordingly, in the cost-optimal methodology, the CO_2 emissions associated to the primary energy consumption of the building have to be evaluated and the related cost savings to be considered in the global costs for the societal (macro-economic) evaluation. While the methodology does not consider CO_2 emissions, the nZEB definitions should take them into account to ensure sustainability and to establish a common umbrella for all MS national approaches[2].

By consequence, it will be useful to consider CO_2 emissions when implementing the cost-optimal methodology and to select further measures and support policies for certain building technologies and packages.

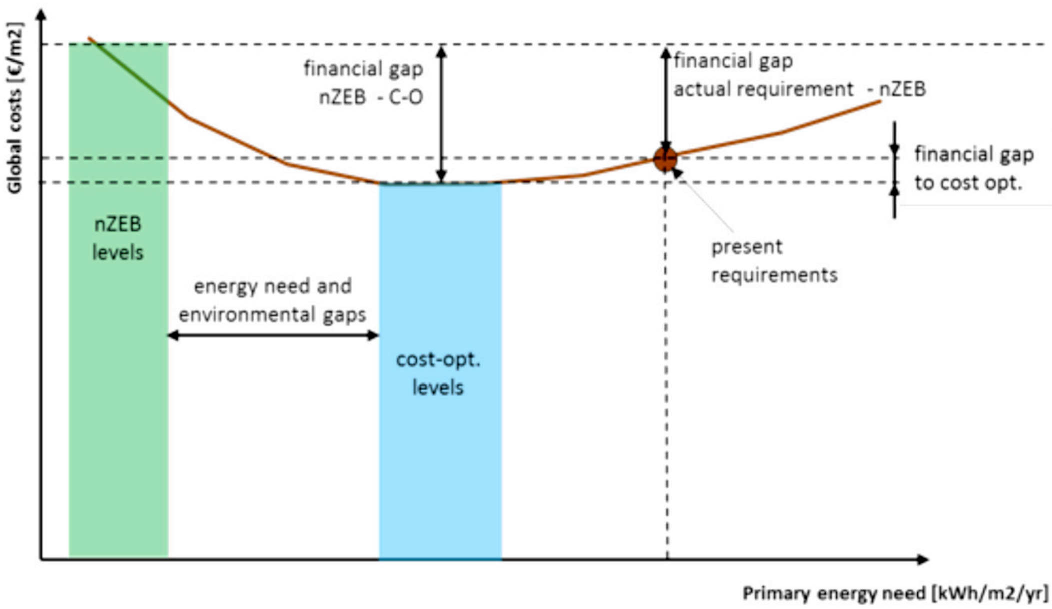
[1] According to the findings from *Roadmap for a competitive low-carbon economy*, the minimum CO_2 reduction in residential and services sectors has to be at 88%-91% by 2050, as comparing to 1990 levels. As it had been presented in BPIE 2011 study on *Principles for nearly Zero-Energy Buildings,* the nZEB definition has to cope with long term the environmental and climate goals. Starting from CO_2 emissions for the building sector of approximately 1.100 Mt CO_2 in 1990 (direct and indirect emissions for heating, domestic hot water and cooling purposes) and assuming a useful floor area in 2050 of 38 billion m^2 in 2050, a 90% decrease of emissions would require an average CO_2 emissions of maximum 3 kg $CO_2/(m^2yr)$: 1,100Mt CO_2 x (100%-90%) / 38 billion m^2 = 2.89 kg/(m^2yr).

[2] For instance the UK strategy for nZEB aims to implement zero carbon buildings by 2016, putting then the main emphasis rather on carbon than on energy need of the building.

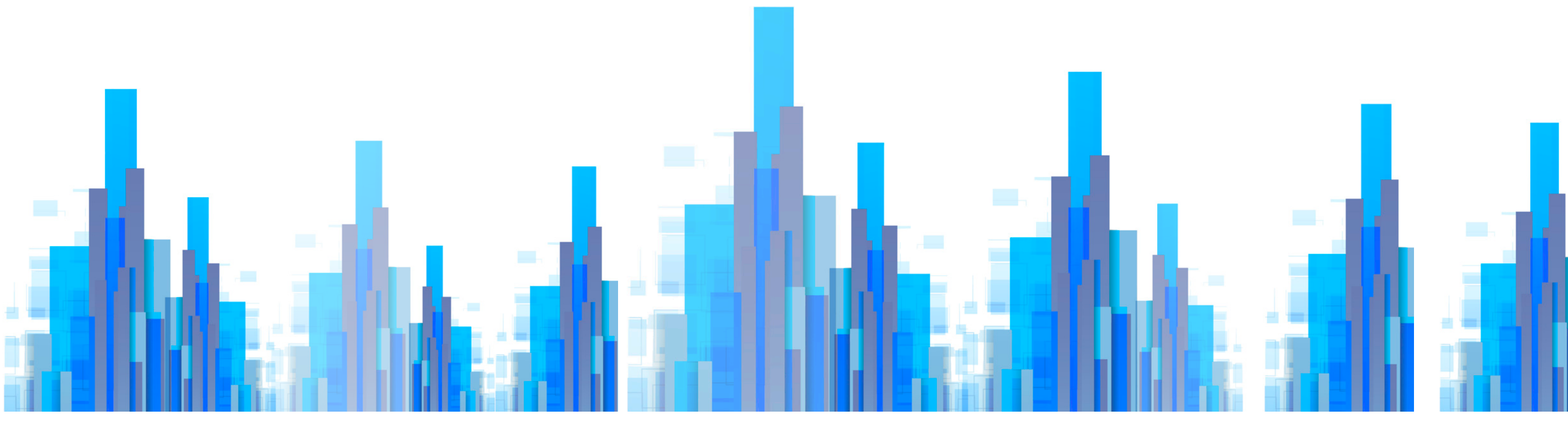
The implementation of cost-optimality nowadays allows highlighting existing gaps which need to be addressed over the following years. By evaluating packages of insulation and heating variants leading towards nZEB levels with the cost-optimal methodology, it will be possible to identify three types of potential gaps to be addressed by 2020 (figure 4):

- Financial gap, i.e. the actual cost difference between cost-optimal and nZEB levels;
- Energy performance gap, i.e. the difference between primary energy need at cost-optimal and nZEB levels;
- Environmental gap, i.e. the difference between associated CO_2 emissions to primary energy need of cost-optimal and nZEB levels, the latter aiming to nearly zero-carbon emissions (or <3kg $CO_2/m^2/yr$) in order to be consistent with the 2050 decarbonisation goals of the EU.

Figure 4: Example of financial, energy and environmental gaps between current and cost-optimal requirements and nZEB levels



The existing gaps between cost-optimal levels and nZEB definitions might need to be bridged. The most influential factors to be addressed are technology and installation costs. The market deployment of more energy efficient and renewable technologies and materials should be stimulated as this could lead to lowering the costs by 2020.



6. PRACTICAL EXAMPLES OF COST-OPTIMAL CALCULATION FOR AUSTRIA, GERMANY AND POLAND

To identify the implications of different factors in implementing the cost-optimal methodology in Member States, a number of practical calculations were performed for Austria, Germany and Poland. The national calculations were elaborated by a group of local experts with a strong expertise in the field of energy efficiency and cost-optimality and are presented in three country reports.

While only a summary of these country reports is presented here, the complete national reports will be made available on the BPIE website (www.bpie.eu).

All three reports were based on common assumptions; however, different national contexts and actual approaches were applied where relevant.

For each country, the cost-optimal evaluation was done only for one or two types of new residential buildings, i.e. for Single-Family Housings (SFH) and/or Multi-Family Housings (MFH). The reference buildings were defined based either on official assumptions or on the country experts' opinions. Where possible, the official calculation methodology was applied in order to be as much as possible in line with the country national approach. The cost-optimal calculation was performed mainly in terms of energy performance of the building.

The current building standards were the reference for the cost-optimal evaluation for both energy performance and global costs. The calculations were done on variants and packages of measures that comprise improved thermal performance as well as heating and ventilation solutions. The proposed variants were defined at each country level and, where possible, built on existing building standards.

Among the calculated packages of measures, there were some very ambitious ones towards nZEB levels. If no national level for the nZEB has yet been defined in the country, several variants/packages significantly improving the actual practice were considered for the cost-optimal analysis.

The calculation was performed for both private and the societal/macroeconomic perspectives as required by the *EU Cost-Optimal Regulation.*

The energy scope covered by the cost-optimal calculation was –according to EPBD- the energy need for heating, ventilation, domestic hot water and auxiliary equipment for the building's operation.

The energy price scenarios and discount rates were in line with both national approaches and recommendations of the *Cost-Optimality Delegated Regulation.* Additionally, more ambitious discount rates and variations of energy price development were used to identify these factors' influence on the cost-optimal calculation. While for Germany and Austria the basic assumptions were quite the same, for Poland there were some differences coming from the national context (Table 1). For Germany, a very low energy price development was considered at national level due to recent increases, which have resulted in an already high electricity price.

Table 1: Basic assumptions for discount rates and energy prices scenarios

Country	Parameter	Basic scenario	Sensitivity analysis
Austria	Discount rate	3.0 %/a (real)	1.0 %/a (real)
	Energy price development	2.8 %/a (real)	4 %/a (real)
Germany	Discount rate	3.0 %/a (real)	1.0 %/a (real)
	Energy price development	2.8 %/a (real)	4.3 %/a (real). 1.3% (real)
Poland	Discount rate	3.0 %/a (real)	5.0 %/a (real)
	Energy price development	6.0 %/a (real)	2.0 %/a (real)

Investment and running (maintenance) costs were considered in all countries. Disposal costs were also included for Germany.

For the macroeconomic/societal calculations, carbon prices were used, -as set out in Annex II of the *Cost-Optimality Delegated Regulation*-, and all taxes excluded, as recommended.

All input parameters used for the cost-optimal calculation are detailed in Annex II.

6.1. COST-OPTIMAL CALCULATION FOR AUSTRIA

In this section, the main findings are presented. A full version of the cost-optimal calculation study for Austria can be found on BPIE website www.bpie.eu.

6.1.1. Reference buildings

The reference building chosen for the Austrian case study is a newly constructed multi-family residential building (MFH).

Table 2 summarises the main characteristics of the reference building, being a typical medium-size multi-family building in an urban or sub-urban context, respectively.

Table 2: Characteristics of the reference building – Multi-family house in Austria

Data name	Quantity	Unit	Comment
Building Geometry	See comments		12x32x18m. 6 floors S/V Ratio = 0.34 1/m Facade N = 576 m^2 Facade E = 216 m^2 Facade S = 576 m^2 Facade W = 216 m^2 Flat roof = 384m^2 Ground floor = 384 m^2
Conditioned gross floor area	2.304	m^2	
Description of the building	See comments	---	Residential building, reinforced concrete with external insulation, heating and hot water combined

Lessons learned

Although typical characteristics of MFH built in Austrian cities were taken into account when selecting the reference building, representativeness -in a narrow sense- cannot be achieved if only one reference building is selected per building category. A more comprehensive and representative picture on cost-optimality would require calculations for a few different sizes and forms of multi-family buildings reference. On the other hand, it seems that the impact of the precise definition of the reference building on cost-optimal levels should not be over-estimated. At least this can be concluded from several comparison calculations, which have been executed in Austria for small multi-family buildings (with about 580 m^2 floor area). The results referring to cost-optimality are very similar to those of the larger multi-family houses presented below.

6.1.2. Selection of variants for building envelope and equipment

Altogether 50 different technical variants were defined. The elements of differentiation are as follows:

Thermal quality of building envelope

Five different levels of insulation standards were defined – starting with heating energy demand HWB-line 16, representing the minimum requirement according to the actual building regulation, and ending up at HWB-line 8, which is representative for the thermal quality of the passive house standard. HWB-line means, in this context, the level of achieved Net Heating Demand (NHD) lines, which, according to the Austrian standards defines the thermal quality of the envelope regardless of the compactness of the building[3].

The actual building regulation in Austria (OIB6-2011)[4] for new residential buildings foresees a minimum requirement of up to 54.4kWh/m^2/yr, according to the building geometry. For building components, the maximum U-values for new residential buildings are 0.35 for external walls, 0.2 for roofs, 0.4 for floors and 1.4 for windows.

In order to derive the variations in the thermal quality of the envelope, the single building elements (window, wall, ground floor, ceiling etc.) were improved step by step in a coherent way. The variation of the thermal quality (variants V1 to V5) was the basic variation which was then repeated in combination with other technical measures as described below.

Heat supply

In the standard package (basic variants V1 – V5), district heating was used as the heat supply system. This system was changed into a condensing gas boiler (V6 – V10), a biomass boiler (V11 – V15) and a heat pump system (V16 – V20). In order to illustrate the differences of district heating systems in terms of primary energy factors, variants V21 – V50 introduced the case of a district heating system mainly based on highly efficient CHP (e.g. for the district heating system in Vienna). Whereas a "standard" district heating system was calculated with a conversion factor of 0.92, district heating systems based on highly efficient CHP were calculated with a value of 0.3. In all cases, the dwellings supply systems were installed as central heating systems including central tap water supply (storage and circulation pipes).

Insulation material

Whereas the basic variants V1 – V5 were calculated with EPS, an additional set of variants V26 – V30 was calculated with mineral rock wool insulation. It was assumed that the 20% additional costs for the insulation material would be incurred.

[3] In order to derive the Net Heating Demand (NHD), the building's geometry also has to be considered. Therefore, the Austrian building regulation defines the NHD as follows: NHD = HWB-Line x (1+3/lc) where lc is the reciprocal value of the surface-volume-ratio of the building.

[4] OIB6-2011 is in force in four federal states since January 1, 2013, while other states are still preparing the implementation.

Share of window area

Variants V31 – V35 diversified the window area of the reference building since this characteristic had a major influence on the NHD. Several sub-variants (10%, 15%, 30% and 40% of window area) were calculated as compared to the 20% share of window area in the basic variants.

Ventilation system

The installation of a mechanical ventilation system with heat recovery is typical for building and energy concepts of low-energy as well as passive houses. This allows significant reduction of ventilation heat losses. In contrast, however, there were higher investment costs as well as increased operation and maintenance costs for this facility. Whereas the basic variants V1 – V5 did not include ventilation systems, variants V36 – V40 introduced this device with an assumed heat recovery rate of 65%. This technical system variation also influenced the heat distribution system inside flats and the required level of air tightness. V36 to V38 require a static heat distribution system (radiators) in parallel to the ventilation system, since the quality of the envelope was not sufficient to heat the dwelling through the ventilation system alone. V40, with the highest level of envelope quality, could elude the static heat distribution system, which means that the investment for the radiator system inside the flat was avoided. This variant, which represents an ideal-typical passive house concept, requires only one heat battery per flat as part of the ventilation system to reheat the air. V39 represents an "interim solution" where the static heat distribution system can be reduced to one radiator per flat. Regarding air tightness, a value of 1.0 was assumed for the variants V36 – V38 – as compared to 1.5 in the basic variants – whereas variants V39 and V40 require even higher levels of air tightness with a value of 0.6. The different air tightness levels were also reflected in the investment costs.

Renewable energy sources

Variants V41 to V50 introduced solar systems, either as solar-thermal system (100 m^2 collector surface) or as a mixture of solar-thermal and PV (50 m^2 collector surface each). In addition, these solar systems were combined first with the district heating system of the basic variants and then with the biomass boiler.

Table 3: Summary of technical variants that were considered

No.	Measure	V1	V2	V3	V4	V5
1	Insulation standards	HWB 16 (present building regulation)	HWB 14	HWB 12	HWB 10	HWB 8
1a	Thermal insulation - Roof	U 0.15	U 0.15	U 0.13	U 0.12	U 0.10
1b	Thermal insulation - Wall	U 0.27	U 0.21	U 0.15	U 0.11	U 0.08
1c	Thermal insulation - Basement	U 0.30	U 0.25	U 0.22	U 0.15	U 0.10
1d	Window	U 1.20 g 0.60	U 1.15 g 0.60	U 1.10 g 0.60	U 1.00 g 0.55	U 0.75 g 0.50
2	Insulation material	EPS	EPS	EPS	EPS	EPS
3	Share of window area	20% N+S: 36% E+W: 14%	20% N+S: 36% E+W: 14%	20% N+S: 36% E+W: 14%	20% N+S: 36% E+W: 14%	20% N+S: 36% E+W: 14%
4	Heating emission	Radiator	Radiator	Radiator	Radiator	Radiator
5	Heat supply	District heating (CHP)	District heating (CHP)	District heating (CHP)	District heating (CHP)	District heating (CHP)
6	Ventilation system	No	No	No	No	No
7	Air tightness	1.5	1.5	1.5	1.5	1.5
8	Solar systems	No	No	No	No	No
No.	**Measure**	**V6**	**V7**	**V8**	**V9**	**V10**
5	Heat supply	Condensing gas boiler	Condensing gas boiler	Condensing gas boiler	Condensing gas boiler	Condensing gas boiler
No.	**Measure**	**V11**	**V12**	**V13**	**V14**	**V15**
5	Heat supply	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)
No.	**Measure**	**V16**	**V17**	**V18**	**V19**	**V20**
5	Heat supply	Heat pump	Heat pump	Heat pump	Heat pump	Heat pump
No.	**Measure**	**V21**	**V22**	**V23**	**V24**	**V25**
5	Heat supply	District heating (CHP high efficient)	District heating (CHP high efficient)	District heating (CHP high efficient)	District heating (CHP high efficient)	District heating (CHP high efficient)
No.	**Measure**	**V26**	**V27**	**V28**	**V29**	**V30**
2	Insulation material	Mineral wool	Mineral wool	Mineral wool	Mineral wool	Mineral wool
No.	**Measure**	**V31**	**V32**	**V33**	**V34**	**V35**
3	Share of window area	a) 10% b) 15% c) 30% d) 40%	a) 10% b) 15% c) 30% d) 40%	a) 10% b) 15% c) 30% d) 40%	a) 10% b) 15% c) 30% d) 40%	a) 10% b) 15% c) 30% d) 40%
No.	**Measure**	**V36**	**V37**	**V38**	**V39**	**V40 (Passive House)**
6	Ventilation System	Mech. 65% heat recovery	Mech. 65% heat recovery	Mech. 65% heat recovery	Mech. 65% heat recovery	Mech. 65% heat recovery
4	Heating emission	Radiator	Radiator	Radiator	Air, one radiator	Air
7	Air tightness	1.0	1.0	1.0	0.6	0.6
No.	**Measure**	**V41**	**V42**	**V43**	**V44**	**V45**
10	RES	100 m² Therm.	100 m² Therm.	100 m² Therm.	50 m² Therm. 50 m² PV	50 m² Therm. 50 m² PV
No.	**Measure**	**V46**	**V47**	**V48**	**V49**	**V50**
5	Heat supply	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)
10	RES	100 m² Therm.	100 m² Therm.	100 m² Therm.	50 m² Therm. 50 m² PV	50 m² Therm. 50 m² PV

Packages of measures at nearly zero-energy levels

Although there has already been an intensive discussion process at the technical level as well as at the policy level, to date the responsible bodies have not presented an official definition of the nZEB term in the Austrian building regulation. Therefore, it was difficult to classify whether a specific variant fulfils the criteria of a nearly-Zero Energy Building or not. However, based on the definition given in the EPBD, a confident proposition to such a classification can be presented:

- The criteria of very high energy performance would most probably be fulfilled by every variant which is at a level of HWB-line 10 or better, especially if combined with a ventilation system with heat recovery.
- The requirement of a significant coverage rate by energy from renewable sources (including energy from renewable sources produced on-site or nearby) would be most probably fulfilled by all variants equipped with either a biomass boiler, or a heat pump or with solar systems (thermal or PV).
- With respect to low CO_2-emissions, besides the variants with a high RES share (as mentioned above), the variants supplied by district heating based on highly efficient CHP also qualify.

6.1.3. Primary energy demand calculation

Calculation procedure

In order to assess the building energy performance, the Austrian standards (relating to building regulation) were applied. Therefore, the method used for the cost-optimal calculation was based on the calculating method for the buildings energy performance in Austria: ÖNORM B 8110-6, and ÖNORM H 5056 – 5059. The standards also include the applicable conversion factors from final energy to primary energy. In addition, the location of Vienna was chosen (heating degree days of 3,459), being quite representative of the average Austrian climate.

Energy scope considered in the cost-optimal calculation

The energy need considered in the calculations included the energy for heating, domestic hot water, ventilation and auxiliary systems of the building. Energy consumption for cooling purposes was not taken into account, because the Austrian building regulation prescribes that residential buildings have to be built in such a way that demand for cooling is avoided. Furthermore, the consumption of electric household appliances was not included in the calculations below[5].

Conversion factors for primary energy

The conversion factors for primary energy are fixed by relevant Austrian standards as follows:

Electricity:	2.62
Gas:	1.17
District heating (CHP):	0.92
District heating (highly efficient CHP):	0.30
Biomass (Pellets):	1.08

6.1.4. Global cost calculation

Basic assumptions

The calculation period was specified in the *Cost-Optimality Delegated Regulation*. For residential buildings, it was defined as a period of 30 years. Overall, it should be noted that the impact of the chosen observation period on the end result is limited due to the consideration of the residual values of the various building elements at the end of the observation period, which is also prescribed in the *Delegated Regulation for Cost-Optimality*.

[5] The energy consumption for electric household appliances is yet included in the primary energy and CO2 values includes in the energy certificate (with a fixed number)

Construction and maintenance cost

Construction and maintenance costs data were founded primarily on a market-based analysis which e7 conducted together with the company M.O.O.CON. The analysis serves to establish a database for the assessment of life-cycle costs applied in early planning phases. It is based on building elements and their related costs. The enquiry of construction cost data started in 2010 and has been continuously updated; involving several construction companies (Hofer, Herzog, 2011). With respect to the costs of ventilation systems in multi-family houses, where there is actually rather limited market-based data available, a few additional sources of information based on scientific literature were used (Schoberl, 2011 & Schoberl, Lang, Handler, 2012).

- *Construction costs related to the building envelope quality*
  The input factors associated with the thermal properties of the building envelope are summarized in Table 4. U-values for façade, roof and basement ceiling insulation as well as their incurred costs were allocated to the five different levels of net heat demand lines – called HWB-line 16, HWB-line 14, HWB-line 12, HWB-line 10 and HWB-line 8. Only those elements were recognized as costs. Costs were different for the analysed variants.

Table 4: Assumed construction cost dependent on quality of the building envelope

	VARIANTS 1-5 (stepwise improvement of the envelope)	
THERMAL INSULATION	U-value [W/m²K]	COSTS [€/m²]
Façade insulation		
HWB-line 16	0.27	66
HWB-line 14	0.21	70
HWB-line 12	0.15	78
HWB-line 10	0.11	89
HWB-line 08	0.08	113
Roof insulation		
HWB-line 16	0.15	185
HWB-line 14	0.15	185
HWB-line 12	0.13	195
HWB-line 10	0.12	201
HWB-line 08	0.10	218
Cellar ceiling insulation		
HWB-line 16	0.30	40
HWB-line 14	0.25	50
HWB-line 12	0.22	56
HWB-line 10	0.15	70
HWB-line 08	0.10	80
Windows		
HWB-line 16	1.20	537
HWB-line 14	1.15	540
HWB-line 12	1.10	544
HWB-line 10	1.00	551
HWB-line 08	0.75	650

For the basic variants, EPS was used as insulation material. For the variants V26 to V30 mineral wool was used instead. For these variants, a general extra cost of 20% was assumed, which is in line with information from construction firms in Austria.

- *Construction and maintenance costs related to heating, ventilation and solar systems*

Table 5 gives an overview on the cost assumption related to the building systems.

Table 5: Cost assumptions related to heating, ventilation and solar systems

VENTILATION SYSTEM	**CONSTRUCTION COST [€/m²GFA]**	**MAINTENANCE [€/m²GFA]**	**YEARLY REPAIRS [€/m²GFA]**
Air ducts and other long lasting elements	35	0	0
Ventilation plant (in case of a parallel static heating system)	20	0.5	0.2
Ventilation plant (for the heating of the building)	25	0.5	0.25
HEATING SYSTEM (Cost data valid for heat load between 45 and 80 kW)	**CONSTRUCTION COST**	**MAINTENANCE [€/a]**	**YEARLY REPAIRS [€/a]**
Gas condensing boiler	155 €/kW	255	385
District heating: transfer station	100 €/kW	150	150
Biomass boiler	550 €/kW	500	600
Heat pump	325 €/kW	250	400
Geothermal probe for heat pump	775 €/kW	-	-
Heat distribution system in the flat (incl. radiators)	30 €/m²GFA	-	-
SOLAR-THERMAL SYSTEM	**CONSTRUCTION COST** [€/m²collector area]	**ANNUAL MAINTENANCE** [€/m²collector area]	**YEARLY REPAIRS** [€/m²collector area]
100 m² collector area	500	3.75	1.67
50 m² collector area	550	3.75	1.67
PHOTOVOLTAICS SYSTEM	**CONSTRUCTION COST** [€/m²collector area]	**ANNUAL MAINTENANCE** [€/m²collector area]	**YEARLY REPAIRS** [€/m²collector area]
	340	1.0	-

For variants V39 and V40 (passive house concepts), the cost for the heat distribution system inside the flat was adapted. V39 calculates with a reduced cost of 10 €/m² (for the single radiator that is still necessary). V40, with exclusive air heating, does not take into account any cost for the static heat distribution system in the flat.

Energy prices and energy price development

As far as the starting year of 2012 is concerned, the following average energy prices are stated:

- **District heating:** 0.11 € / kWh. For simplification, a mixed price between work and power input was applied. The meter charges were not included as they do not depend on the building thermal-energy performance. The stated mixed price was compared to several heating rates and belongs more to Austria's higher heating rates. For instance, based on the reference building, a price of just about 0.10 €/kWh is obtained for district heating in Vienna.
- **Gas price:** 0.07 €/kWh. This price is a mixed price too.
- **Biomass / pellets price:** 0.05 €/kWh.
- **Electricity:** Different prices apply here – once again calculated on a mixed basis for work and power. As specified in Table 6, a standard price was assumed for auxiliary electricity consumption (for the operation of the ventilation system and the boilers). A special cheaper tariff was assumed for heat pumps. Finally, a feed-in tariff for electricity of the PV-plant (not used in the house itself) was taken into account.

Regarding the annual increase of energy prices, the assumption was 2.8% in the reference scenario. This assumption was differentiated in the sensitivity analysis. Another case for the sensitivity analysis was the energy price assumption for the macroeconomic (societal) perspective in which practically the same prices were applied but with exclusion of the value added tax.

Table 6: Financial calculation results, VAT included

Parameter	Value for calculation	Comments/Source
Gas	0.07 EUR/kWh	Assumption
District heating	0.11 EUR/kWh	Assumption
Biomass (Pellets)	0.05 EUR/kWh	Assumption
Electricity	0.19 EUR/kWh	Assumption
Electricity (special tariff heat pump)	0.16 EUR/kWh	Assumption
Electricity (feed-in tariff)	0.10 EUR/kWh	Assumption
Energy price development	2.8 %/a	In real term

Table 7: Macroeconomic view, without VAT

Parameter	Value for calculation	Comments/Source
Gas	0.058 EUR/kWh	Assumption
District heating	0.092 EUR/kWh	Assumption
Biomass (Pellets)	0.042 EUR/kWh	Assumption
Electricity	0.158 EUR/kWh	Assumption
Electricity (special tariff heat pump)	0.133 EUR/kWh	Assumption
Electricity (feed-in tariff)	0.083 EUR/kWh	Assumption

Discount rates

As for the discount rate, the *Cost-Optimality Delegated Regulation* provides Member States with a wide scope for national application. In this analysis, the discount rate was set at 3% in real terms. This approach reflects the current interest rates for long-term mortgage secured loans and should be regarded as a realistic underlying asset – depending on the client's creditworthiness and his expected profit. The influence of different discount rates on the calculation result was examined with a sensitivity analysis.

Other relevant input parameters

- The building elements lifetime was differentiated at the level of building elements. This also means that major system elements may have different lifetimes (e.g. the heating boiler has a shorter lifetime than the heat distribution system). Table 8 presents the most important assumptions regarding the building elements lifetime.
- In real terms, it was assumed that the price for maintenance and replacement would not increase – i.e. the nominal price increase, which will occur overtime, will be in line with the general inflation rate.
- Since the construction cost, as presented above, does not include the cost for design, an average 10% additional cost for design was assumed.

Table 8: Assumed life-times of building elements

Parameter	Value for calculation
Insulation (thermal protection) Measures related to air tightness	50 years
Windows	35 years
Heating and ventilation distribution	35 years
Heat plant, central ventilation system	20 years
Heat pump, earth loop	50 years

6.1.5. Cost-optimal calculation from the financial perspective

Based on the above mentioned assumptions, the variants life cycle costs were determined in accordance with the approach outlined in the respective EU regulations. The life cycle costs include the construction costs, upkeep costs, maintenance costs, renewal costs for those building elements that need to be replaced within the observation period, as well as energy costs. In addition, residual values at the end of the calculations period were taken into account. In the figures 5-10, the essential calculation results for the baseline scenario are presented. The figures show the global cost differences compared to the actual minimum requirements (according to building regulations), which are at the level of NHD line HWB-line 16.

The main results are:

- First, it should be noted as a general point that the cost curves for comparable variants are extremely shallow. If one looks, for example, at the cost curve for the basic variants which represents a stepwise improvement of the building envelope starting from actual minimum requirements (HWB-line 16; V1) and ending up at a passive house envelope (HWB-line 8; V5), the cost range is only at a level of about 20 €/m² over the whole calculation period of 30 years. This represents just 5 cents/m² per month. The basic variants have a very slight cost-optimum at the net heating demand line HWB-line

12. However, the cost differences are very low, especially in the area between NHD lines 10 to 14. It is also true that concerning the reference building supplied with district heating, the HWB-line 8 is not far from the cost-optimum (see Figure 5).

- When analysing the impact of different heating systems, one can notice that the general picture remains widely unchanged. In the range between NHD lines 14 and 10, the cost curve is extremely shallow. Only when comparing the NHD line 8 to the cost-optimum, a slight "cost jump" can be seen for the reference buildings supplied by gas, biomass and heat pump. This is simply due to cheaper variable energy costs as compared to the variants with district heating (see Figure 6, left).
- The choice of insulation material has practically no influence on the cost-optimal level (see Figure 6, right).
- The variants where window areas were diversified (see Figure 7) show that the forms of the cost curves do not change remarkably. On the other hand, however, the figure demonstrates clearly how global costs jump up with increasing window areas.
- Regarding the variants with ventilation system, those concepts were the cheapest when an additional static heating system was omitted, since the cost of heating distribution can be reduced in this case. This is even true if one considers that air heating concepts are only feasible if the building has a very good envelope quality (see Figure 7, left). The global cost of the most efficient variants with ventilation system was about 30 to 40 €/m^2 higher than of comparable variants without ventilation systems. However, it has to be underlined that the application of ventilation systems offers a significant advantage with respect to user comfort and mould prevention.
- The basic variants featuring solar systems proved to be rather cost-effective and also led to a significant improvement in the primary energy demand. In the case of the reference building with district heating, the variant V43 (NHD 12 combined with a solar-thermal system) turned out to be the cost-optimum for all variants examined within the scope of the baseline scenario. The picture was a bit less favourable for the variants, when solar systems were combined with biomass heating systems. But even these variants were very close to the cost-optimum (see Figure 7).
- Altogether one can conclude that several variants featuring major characteristics of nearly-Zero Energy Buildings – very high energy performance; low amount of energy covered to a very significant extent by energy from renewable sources; low CO_2 emissions – were very close to the cost-optimum. Therefore, one could derive a summary recommendation for policy: a further tightening of the current minimum requirements in building regulations could be implemented without effecting substantial global cost increases over the life cycle. The increased amount of construction costs would be entirely – or at least for the most part – offset by lower operating costs.

Figure 5 : Results of cost-optimal calculation for the basic variants: stepwise improvement of the thermal quality of the building envelope, ranging from actual minimum requirements (HWB 16; V1) to passive house envelope (HWB 8; V5); global cost difference compared to actual minimum requirements

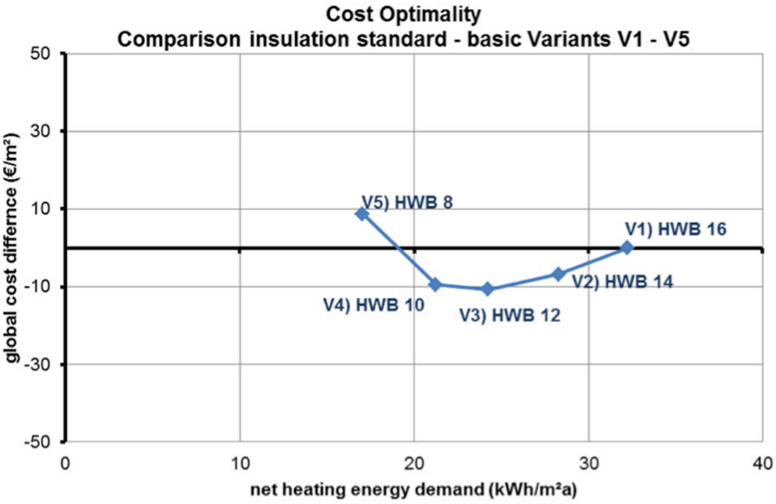


Figure 6 : Results of cost-optimal calculation for different envelope qualities with different heat supply system and materials– global cost difference compared to actual minimum requirements

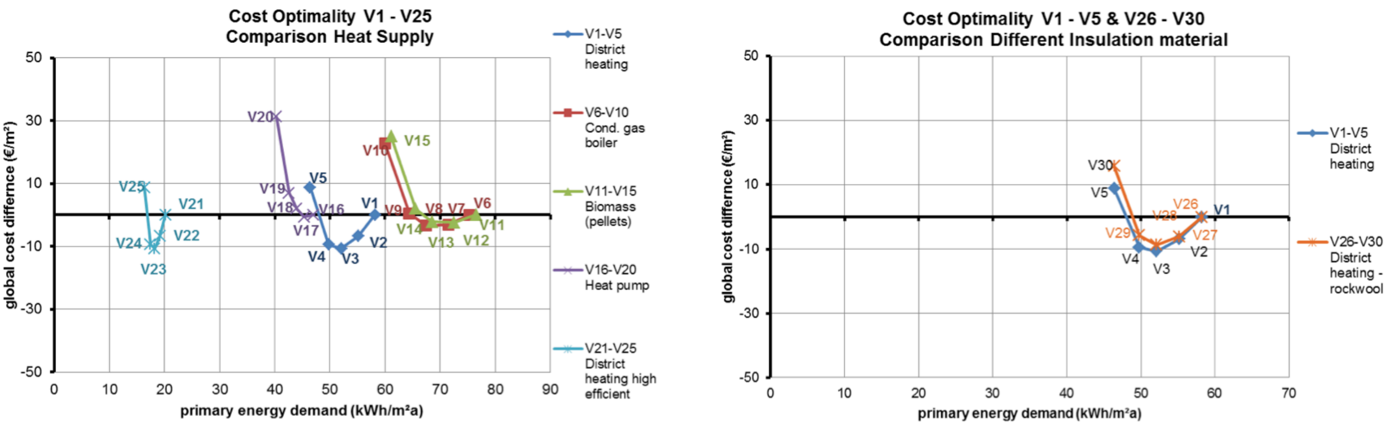


Figure 7 : Results of cost-optimal calculation for different assumptions with respect to the share of window area share – global cost difference compared to actual minimum requirements

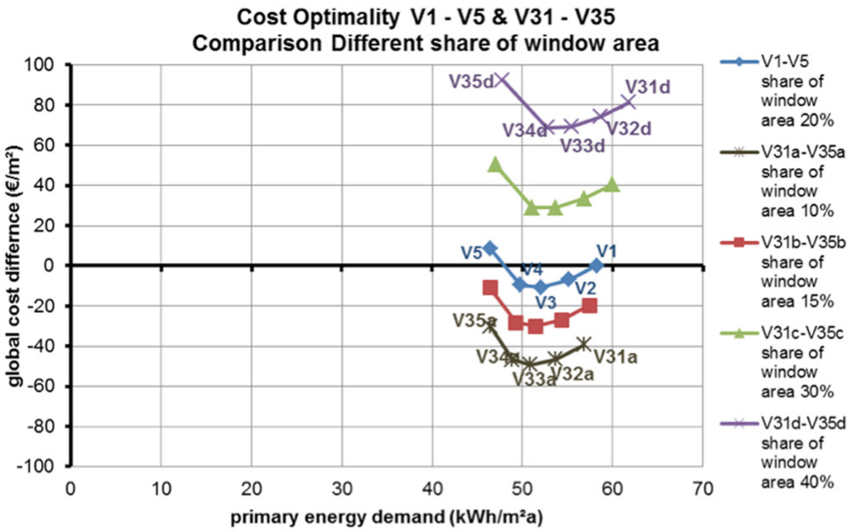
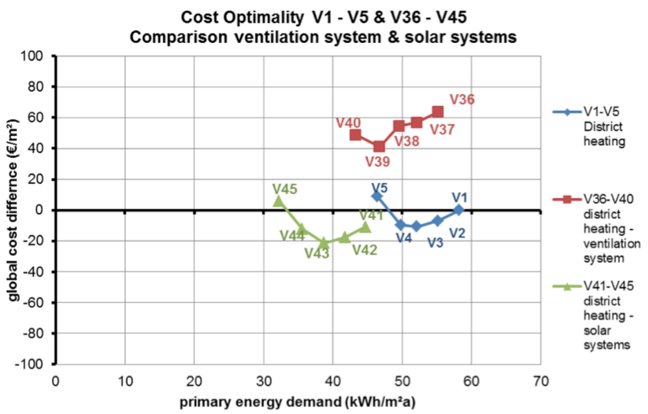
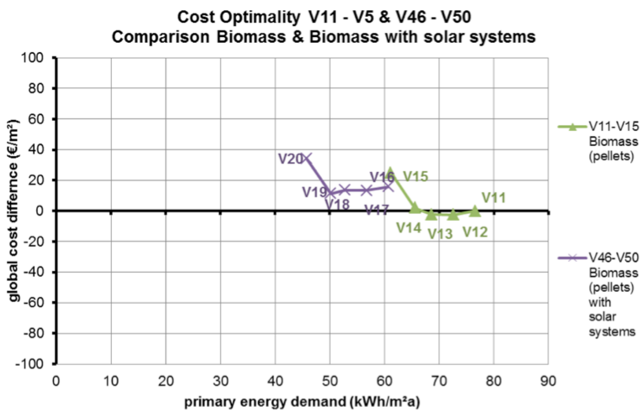


Figure 8 : Results of cost-optimal calculation for the basic variants (district heating) combined with ventilation and solar systems (left side graph) as well as for the variants of biomass heated building combined with solar systems (right side graph) – global cost difference compared to actual minimum requirements





6.1.6. Sensitivity analysis – including results of the macro-economic perspective

In addition to the 50 technical variants described above, a series of sensitivity analyses was conducted in order to check the reliability and stability of the baseline scenario results. With the sensitivity analyses the impact of important framework conditions were tested, such as the discount rate or the energy price development. In order to reduce the effort, the sensitivity analyses were realised only for the variants V1 – V5 (basic variants), V36 – V40 (variants with ventilation systems including the so-called passive house concepts) and V46 – V50 (biomass in combination with solar systems). Table 9 summarises the sensitivity analyses that were carried out.

A specific case was the macroeconomic (societal) perspective, which was conducted with sensitivity analyses Macro1 to Macro3. The differences between these three scenarios of the macroeconomic view refer to variations in the discount rate and in energy price development.

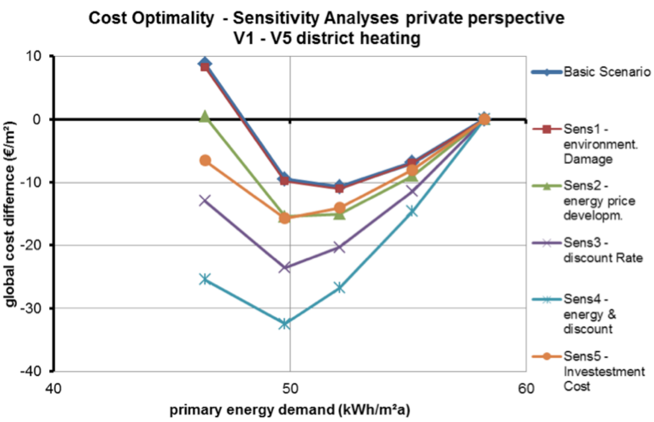
Table 9: Overview on sensitivity analyses conducted

Parameter	Value for basic calculation	Value for sensitivity analysis
Sens1: Cost of environmental damage	0 EUR/tCO_2	Carbon price according to recommended values by the *C-O Regulation* Annex II
Sens2: Energy price development	2.8 % p.a.	4 % p.a.
Sens3: Discount rate	3.0 % p.a.	1.0 % p.a.
Sens4: Discount rate and energy price development	3.0 % p.a. 2.8 % p.a.	1.0 % p.a. 4.0 % p.a.
Sens5: Investment cost		Reduction of difference costs between variants (due to regional cost differential)
Macro1: Macroeconomic-perspective 1	Discount rate 3.0% p.a. Energy price 2.8% p.a. VAT included No subsidies 0 EUR/tCO_2	Discount rate 3.0% p.a. Energy price 2.8% p.a. No tax No subsidies Carbon price according to recommended values by the *C-O Regulation* Annex II
Macro2: Macroeconomic-perspective 2	Discount rate 3.0% p.a. Energy price 2.8% p.a. VAT included No subsidies 0 EUR/tCO_2	Discount rate 1.0% p.a. Energy price 2.8% p.a. No tax No subsidies Carbon price according to recommended values by the *C-O Regulation* Annex II
Macro3: Macroeconomic-perspective 3	Discount rate 3.0% p.a. Energy price 2.8% p.a. VAT included No subsidies 0 EUR/tCO_2	Discount rate 1.0% p.a. Energy price 4.0% p.a. No tax No subsidies Carbon price according to recommended values by the *C-O Regulation* Annex II

Figures 9-11 and Tables 10-12 show the results of the sensitivity analyses in a condensed form. The figures on the left side show the results of the sensitivity analysis regarding the private investor's perspective (basic scenario compared to Sens1 to Sens5). The figures on the right side show the results of the sensitivity analyses related to the macroeconomic perspective (Macro1 to Macro3).

Overall, it can be summarised that the influence of the tested input parameters was almost insignificant mainly with respect to the form of the cost curve and with respect to remarkable shifts of the cost optimum. It should be stressed that the cost curves are still very shallow. From the influence factors tested (and with the assumptions taken) the single most important factor seems to be the discount rate (Sens4), but also the assumed cost differences related to different qualities are important (Sens5). The sensitivity analyses related to the macroeconomic perspective (Macro1 to Macro3) with a combination of low discount rate, exclusion of VAT and inclusion of CO_2-cost show – in general – an improvement of the cost curve mainly with respect to the most efficient solutions – i.e. the variants with the lowest primary energy demand and lowest CO_2-emissions.

Figure 9: Results of the sensitivity analyses for the basic variants (district heating)



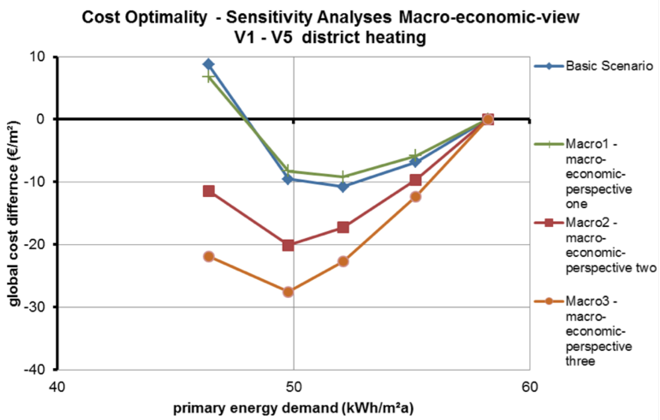


Table 10: Results of the sensitivity analyses for the basic variants (district heating) – cost-optimal variants are highlighted

Sensitivity analyses		V1 HWB 16	V2 HWB 14	V3 HWB 12	V4 HWB 10	V5 HWB 8
Primary energy demand	[kWh/m²a]	58.22	55.17	52.10	49.77	46.41
Gap to HWB 16	[%]		-5.2%	-10.5%	-14.5%	-20.3%
Global cost Basic Scenario	[€/m²]	382.68	375.84	**371.93**	373.16	391.44
Global costs Sens1 - Cost of environmental damage	[€/m²]	385.17	378.21	**374.17**	375.30	393.45
Global costs Sens2 - Energy price development	[€/m²]	422.95	413.97	407.91	**407.50**	423.43
Global costs Sens3 - Discount rate	[€/m²]	442.00	430.62	421.67	**418.45**	429.08
Global costs Sens4 - Energy price & discount rate	[€/m²]	502.82	488.22	476.01	**470.31**	477.38
Global costs Sens5 - Reduction difference invest. cost	[€/m²]	382.68	374.64	368.62	**366.96**	376.14
Global costs Macro1 - Macroeconomic-perspective one	[€/m²]	321.39	315.57	**312.18**	313.11	328.21
Global costs Macro2 - Macroeconomic-perspective two	[€/m²]	371.81	362.16	354.52	**351.70**	360.36
Global costs Macro3 - Macroeconomic-perspective three	[€/m²]	422.50	410.15	399.80	**394.92**	400.62

Figure 10: Results of the sensitivity analyses for the variants with ventilation system

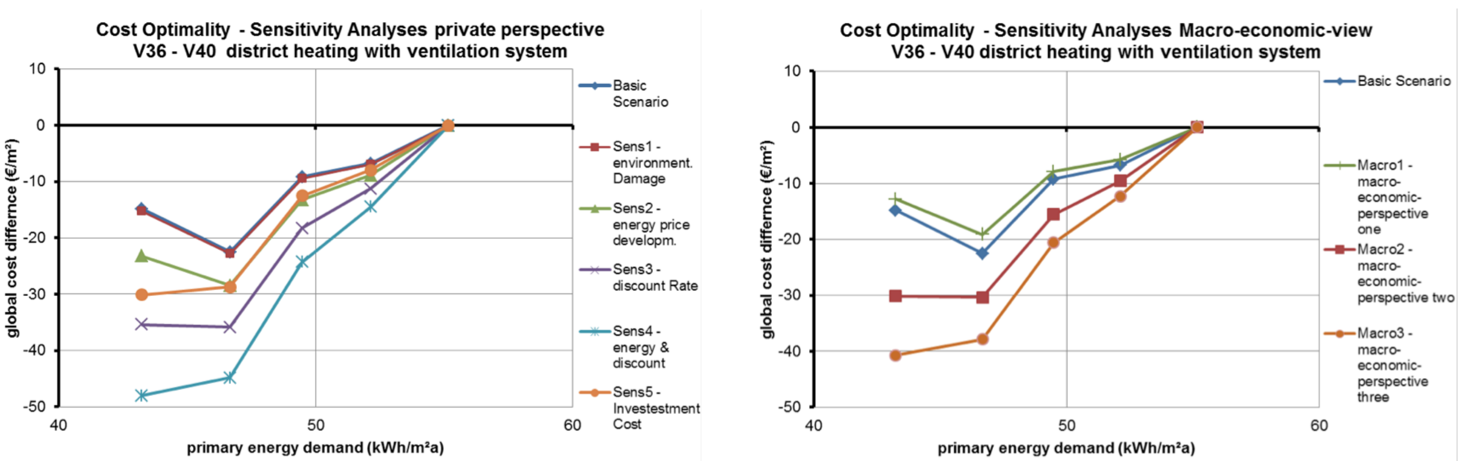


Table 11: Results of the sensitivity analyses for the variants with ventilation system – cost-optimal variants are highlighted

Sensitivity analyses		V1 HWB 16	V2 HWB 14	V3 HWB 12	V4 HWB 10	V5 HWB 8
Primary energy demand	[kWh/m²a]	55.16	52.13	49.48	46.67	43.24
Gap to HWB 16	[%]		-5.5%	-10.3%	-15.4%	-21.6%
Global cost Basic Scenario	[€/m²]	446.51	439.72	437.27	423.99	431.68
Global costs Sens1 - Cost of environmental damage	[€/m²]	449.10	442.19	439.63	426.23	433.78
Global costs Sens2 - Energy price development	[€/m²]	483.18	474.27	469.96	454.70	459.97
Global costs Sens3 - Discount rate	[€/m²]	503.46	492.16	485.20	467.63	468.09
Global costs Sens4 - Energy price & discount rate	[€/m²]	558.85	544.34	534.57	514.00	510.82
Global costs Sens5 - Reduction difference invest. cost	[€/m²]	446.51	438.53	433.96	417.80	416.38
Global costs Macro1 - Macroeconomic-perspective one	[€/m²]	374.68	368.90	366.75	355.57	361.83
Global costs Macro2 - Macroeconomic-perspective two	[€/m²]	423.17	413.57	407.62	392.81	393.00
Global costs Macro3 - Macroeconomic-perspective three	[€/m²]	469.32	457.05	448.76	431.46	428.61

Figure 11 : Results of the sensitivity analyses for the variants with biomass heating system combined with solar systems

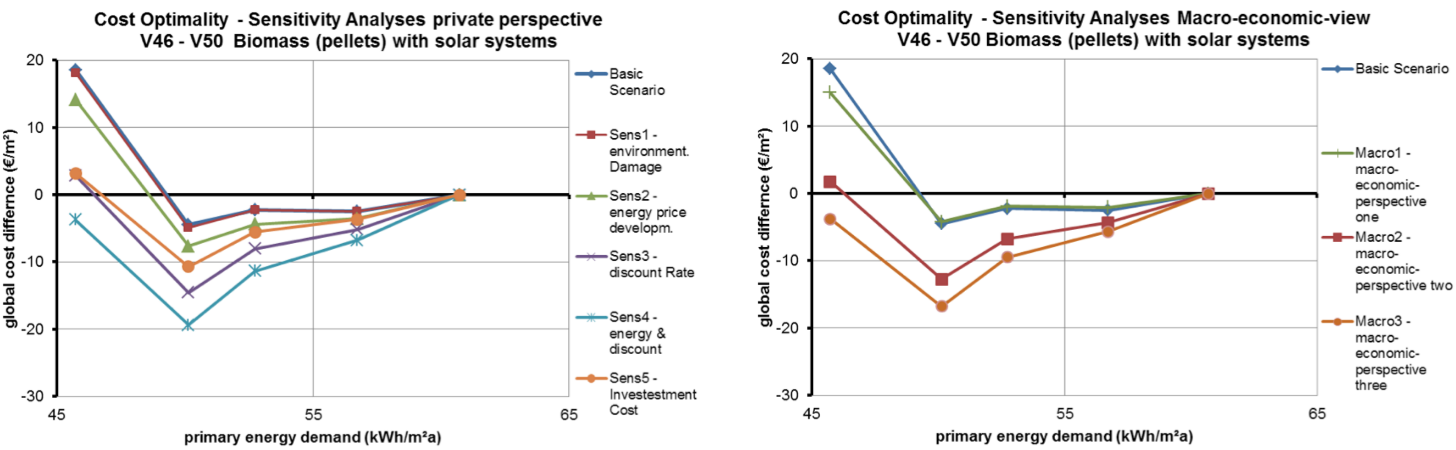


Table 12 : Results of the sensitivity analyses for the variants with biomass heating system combined with solar systems – cost-optimal variants are highlighted

Sensitivity analyses		V1 HWB 16	V2 HWB 14	V3 HWB 12	V4 HWB 10	V5 HWB 8
Primary energy demand	[kWh/m²a]	60.71	56.72	52.73	50.13	45.73
Gap to HWB 16	[%]		-6.6%	-13.1%	-17.4%	-24.7%
Global cost Basic Scenario	[€/m²]	331.02	328.54	328.78	326.54	349.55
Global costs Sens1 - Cost of environmental damage	[€/m²]	331.42	328.93	329.16	326.54	349.55
Global costs Sens2 - Energy price development	[€/m²]	348.01	344.44	343.60	340.34	362.15
Global costs Sens3 - Discount rate	[€/m²]	354.96	349.82	346.90	340.40	357.83
Global costs Sens4 - Energy price & discount rate	[€/m²]	380.61	373.83	369.26	361.24	376.87
Global costs Sens5 - Reduction difference invest. cost	[€/m²]	331.02	327.35	325.47	320.34	334.24
Global costs Macro1 - Macroeconomic-perspective one	[€/m²]	276.25	274.17	274.37	272.05	291.23
Global costs Macro2 - Macroeconomic-perspective two	[€/m²]	296.36	292.05	289.61	283.59	298.11
Global costs Macro3 - Macroeconomic-perspective three	[€/m²]	317.73	312.06	308.25	300.96	313.98

6.2. COST-OPTIMAL CALCULATION FOR GERMANY

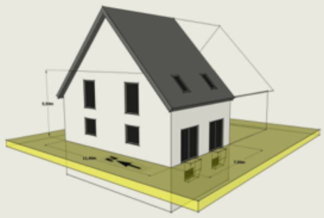
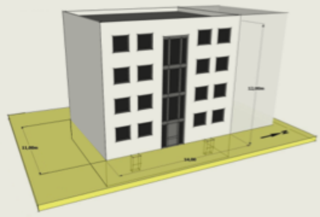
A full version of the cost-optimal calculation study for Germany can be found on BPIE website www.bpie.eu, while the main findings are presented in this section.

6.2.1. Reference buildings

An exemplary single-family building (semi-detached house) and one multifamily building were considered as reference buildings. The respective building data were developed in an earlier study commissioned by BMVBS, with the aim of deriving a set of model buildings being representative for new residential buildings in Germany (ZUB, 2010). IWU, in collaboration with the three involved architect offices, adapted these data and methodology under the scope of a previous project (IWU, 2012), modified definitions of reference buildings (Table 13)[6] and determined the costs of different envelope standards and types of heat supplies.

[6] Detailed characteristics of reference buildings in the required format by the *Cost-Optimality Delegated Regulation* are presented in Annex 2

Table 13: Main characteristics of reference buildings - Single Family House (SFH) and Multi-Family House (MFH) in Germany[7]

Building's characteristics	Single-family building (SFH)	Multi-family building (MFH)
Building sketch		
Heated volume (Ve)	586 m^3	1848 m^3
Heated living space	139 m^2	473.0 m^2
Useful floor area (AN) acc. to EnEV standard	187.5 m^2	591.4 m^2
Surface area (S)	344.5 m^2	776.0 m^2
Surface-area over volume ratio (S/V_e)	0.59 m-1	0.42 m-1

<u>Lessons learned</u>

One of the problems identified regarding the definition of reference buildings was the thermal quality of the building envelope. It was defined without considering basic rules of designing energy efficient buildings. Consequently, IWU had to define several adaptations in accordance with the architects involved, e.g. an inclusion of the top attic space in the thermal envelope (room for installation of heating and ventilation system), raising of the cellar ceiling above ground level (render insulation system can extend below the bottom edge of the cellar ceiling), or the rotation of the building to enable the installation of solar panels facing South.

Another problem emerged: data availability. The determination of cost differences for different supply system variants as well as different insulation and window standards required detailed information which was not provided within the data of the model buildings. The architects involved in the cost determination would have needed at least ground plans and façade views with dimensions to determine specific lengths or areas (sizes of single windows, edge lengths of the roof areas and the facades, etc.). Therefore, when designing reference buildings, it is strongly recommended to develop them in cooperation with architects. The buildings should have common and simple geometries, easy to be reproduced in real life. Moreover, it is useful to design reference buildings based on plans of actually built houses, with simplifications or adaptations when necessary.[8]

6.2.2. Selection of variants for building envelope and equipment

To determine the cost-optimal level for new residential buildings, six different thermal protection standards and the corresponding combinations of insulation measures for the envelope (e.g. insulation of roof, walls, cellar ceiling as well as thermally improved windows) were defined beforehand (tables 14-16) (IWU, 2012). The first and second levels of variants (see Table 14) reflect the thermal protection requirements (secondary condition) of the German Energy Saving Ordinances (EnEV) from 2007 (no longer valid) and 2009[9] (current requirement).

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[7] Picture from the study ZUB (2010) and modified by IWU

[8] Three examples of such real model buildings "re-designed" by an architect to fit the task can be found in: Loga, Tobias; Knissel, Jens; Diefenbach, Nikolaus: *Energy performance requirements for new buildings in 11 countries from Central Europe – Exemplary Comparison of three buildings.* Final Report; performed on behalf of the German Federal Office for Building and Regional Planning (Bundesamt für Bauwesen und Raumordnung, Bonn); in collaboration with e7 / Austria, STU-K / Czech Republic, NAPE / Poland; MDH / Sweden, SBi / Denmark, BRE / UK, BuildDesk / Netherlands, BBRI / Belgium, GLA / Luxembourg, ADEME / France; Institut Wohnen und Umwelt, Darmstadt / Germany Dec. 2008 www.iwu.de/fileadmin/user_upload/dateien/energie/werkzeuge/iwu_report_-_comp_req_new_buildings.pdf

The third level represents the U-values given by the reference specification of the current EnEV 2009[9] (these values are used to calculate the maximum primary energy demand).

The variants 85%, 70% and 55% of "EnEV 2009 U Ref" (levels 4, 5 and 6 respectively) are similar to the three different thermal protection requirements (also as secondary conditions) of the Federal funding scheme for new buildings of the German bank KfW. Additionally, the sixth level represents passive houses U-values.

For all variants, a thermal bridging supplement of 0.02 W/(m²K) was assumed, which is actually easy to reach by observing the basic rules of thermal envelope planning. However, attention should be paid in case of cross-country comparisons; the value can only be compared with values determined on the basis of external dimensions of the building.

Table 14: Building envelope variants

Standard	Variant 1	Variant 2	Variant 3: Reference case	Variant 4	Variant 5	Variant 6
Thermal protection	**EnEV 2007 HT' Max** $\leq H'_{T,zul}$ according EnEV 2007	**EnEV 2009 HT' Max** $\leq H'_{T,zul}$ according EnEV 2009	**EnEV 2009 U Ref** U-Values EnEV 2009 reference building	**EnEV 2009 U Ref 85%** 85% of "EnEV 2009 U Ref"	**EnEV 2009 U Ref 70%** 70% of "EnEV 2009 U Ref"	**EnEV 2009 U Ref 55%** 55% of "EnEV 2009 U Ref" (≈ U-values of passive house)

Table 15: SFH: U-values for selected thermal protection standards

U- value [W/m²K]	Variant 1	Variant 2	Variant 3: Reference case	Variant 4	Variant 5	Variant 6
Roof	0.35	0.30	0.20	0.17	0.16	0.09
Upper ceiling	0.35	0.30	0.20	0.17	0.16	0.10
Wall	0.60	0.40	0.28	0.20	0.20	0.10
Cellar ceiling	0.70	0.50	0.35	0.25	0.20	0.13
Windows	1.50	1.50	1.30	1.30	0.80	0.80
Rooflight	1.80	1.80	1.40	1.40	1.00	1.00
Front door	2.00	2.00	1.80	1.80	0.80	0.80

[9] According to the German energy saving ordinance EnEV 2009, all new buildings have to meet two requirements at the same time:
- Maximum values of the HT/Aenv (heat transfer coefficient by transmission divided by envelope area, tabled depending on building size and neighbour situation).
- Maximum values of QP/Ac,nat (primary energy demand divided by "conditioned floor area" = a synthetical area derived from the building volume by a fixed factor) determined by a reference specification (German expression "reference building" omitted here to avoid confusion), consisting of a table with U-values and a heating system. The maximum primary energy demand is determined assuming the reference specification and calculating the primary energy demand for the distinct building.

A precondition, set by a further law (Erneuerbare Energien Wärme-Gesetz), is that renewable energies are used to a certain extent – otherwise 85% of both conditions are valid.

Table 16: MFH: U-values for selected thermal protection standards

U- value [W/m²K]	Variant 1	Variant 2	Variant 3: Reference case	Variant 4	Variant 5	Variant 6
Roof	0.35	0.24	0.20	0.16	0.18	0.10
Upper ceiling	0.35	0.24	0.20	0.16	0.18	0.10
Wall	0.57	0.32	0.28	0.18	0.20	0.12
Cellar ceiling	0.70	0.35	0.35	0.25	0.25	0.15
Windows	1.50	1.30	1.30	1.30	0.80	0.80
Rooflight	1.80	1.40	1.40	1.40	1.00	1.00
Front door	2.00	1.80	1.80	1.80	0.80	0.80

Furthermore, twelve heat supply variants were included in the packages of measures for cost-optimal calculation, including renewable energies options (Table 17) (IWU, 2012).

Table 17: Variants for heat supply systems

Measures acronyms	Heat supply systems
BWK	Condensing boiler (gas)
BWK+Sol	Condensing boiler (gas) + solar heating system
BWK+WRG	Condensing boiler (gas) + ventilation system with heat recovery
BWK+Sol+WRG	Condensing boiler (gas) + solar heating system and ventilation system with heat recovery
WPE	Electric heat pump / heat source soil
WPE+Sol	Electric heat pump / heat source soil with solar heating system
WPE+WRG	Electric heat pump / heat source soil with ventilation system with heat recovery
WPE+Sol+WRG	Electric heat pump / heat source soil with solar heating system and ventilation system with heat recovery
HPK	Wood pellets boiler
HPK+Sol	Wood pellets boiler + solar heating system
HPK+WRG	Wood pellets boiler + ventilation system with heat recovery
HPK+Sol+WRG	Wood pellets boiler + solar heating system + ventilation system with heat recovery

Overall, 72 packages of measures were created, each one being comprised of a combination of thermal envelope and heating supply system variants.

Packages of measures at nearly zero-energy levels

There is no official nZEB definition yet for Germany. Nevertheless, it can be assumed that the definition will be close to the actual "KfW Effizienzhaus 40" standard (or "efficiency building 40", with primary energy demand = 40% of the current requirements), the most ambitious level of the Federal grant programme for new buildings. In Germany, "Effizienzhaus 40"[10] (EB40) is currently used in varied preparatory studies and scenarios as a widely agreed equivalent of a possible nZEB standard for new buildings by 2020.

The thermal envelope quality of EB40 is similar to that of a passive house. Due to different definitions of global requirements, the technical installations may differ from those of a passive house (e.g. a ventilation system with heat recovery is not mandatory in an EB40).

[10] Besides the primary energy requirements, *"Effizienzhaus 40"* has also defined maximum values for the heat transfer coefficient. To fulfill this requirement, the U-values of opaque elements must typically be in a range of 0.10 to 0.15 W/(m²K) and at around 0.8 W/(m²K) for windows (the actual U-values depend on the building geometry and the thermal bridging losses).

6.2.3. Primary energy demand calculation

Calculation procedure

For the defined packages of thermal protection standards and heat supply systems, the primary energy demand and the energy use were calculated by use of the spread sheet-based tool "EnEV-XL". A basis for the energy performance calculation was the calculation method DIN V 4108-6 along with DIN V 4701-10 – version valid for EnEV 2009. Energy performance results refer to square metres of useful floor area according to EnEV standard[11] (IWU, 2012).

Conversion factors for primary energy

The conversion factors for primary energy used in the case study of Germany are:

Electricity:	2.6
Natural gas:	1.1
Biomass (wood pellets):	0.2

Energy scope considered in the cost-optimal calculation

The energy need considered in the calculations was the energy for heating, domestic hot water, ventilation and auxiliary systems of the building.

Discussion points

The energy performance calculation includes standard assumptions of climatic conditions and user behaviour. These boundary conditions are not necessarily identical with typical or average values of the country.

For example, the German asset rating calculation (EnEV 2009 / DIN V 4108-6) is based on a set-point temperature of 19°C. However, there is evidence that significantly higher temperatures can be typically found in well-insulated buildings, significantly lower in poorly-insulated buildings (new buildings: 20-21°C, existing not-refurbished buildings: 17°C). Since the economic assessment of insulation depends on the assumed room temperature, whether this effect should be considered in the cost-optimal calculations should be discussed. The inclusion of this effect could lead to two different results: a) the assumption of a higher room temperature level for new buildings would presumably result in an improved cost effectiveness of thermal protection in this case and b) assuming realistic room temperatures for non-refurbished old buildings would lead to lower (more realistic) energy savings.

The discussion of reality-based assumptions may in the future also include other boundary conditions, e.g. the shading by buildings or trees nearby (the standard assumption in the German regulation does not consider the shading), the air exchange rates with and without ventilation system etc.

6.2.4. Global cost calculation

Basic assumptions

The cost-optimal calculation was performed over a 30-year period, as specified in the *Cost-Optimality Delegated Regulation*.

For the global cost calculation (financial perspective), the following cost categories were taken into account: initial investment costs, residual value, replacement costs, maintenance costs and energy costs. For the present report:

- All costs included taxes (i.e. VAT).
- Subsidies were not included.
- The calculation was carried out in real terms (inflation adjusted).
- All cost categories were discounted to the beginning of the calculation period (net present value method).

[11] A more detailed description of the calculation methodology is available in the full country report for Germany available at www.bpie.eu

The initial investment costs are important factors for the cost-optimal calculation. Within a previous project (IWU 2012), three architecture and engineering offices were commissioned to investigate costs for thermal protection measures and energy saving installations based on actual cost statements and tenders of recent construction projects. As a result, they provided up-to-date cost functions and cost data that can be used for a broad range of thermal protection standards and for residential buildings of different size (see Table 18 and Table 19)[12].

Table 18: Average costs of increased thermal protection / results of the analyses of cost calculations by three planning offices

	Specific costs of the thermal resistance increased by 1 m^2K/W	Specific costs per cm increased insulation thickness (assuming thermal conductivity of 0.035 W/(mK))
	[€/(m^2K/W)]	[€/cm/m^2]
Flat roof	4.0	1.1
Steep roof	9.5	2.7
Outer wall	5.9	1.7
Cellar ceiling	5.9	1.7
Window	300	-
Roof window	800	-
External door	1100	-

Table 19: Average costs of heat supply system variations / results of the analyses of cost calculations by three planning offices

	SFH	MFH
Heat generator: cost difference compared to system with gas condensing boiler		
Woodpellet boiler	+ 80 €/m^2	+ 31 €/m^2
Electrical heat pump (heat source: ground)	+ 121 €/m^2	+ 60 €/m^2
Heat distribution and emission: cost difference compared to system with standard radiators		
Underfloor heating	+ 20 €/m^2	+ 25 €/m^2
Additional costs of supplemental systems		
Thermal solar DHW system	+ 35 €/m^2	+ 35 €/m^2
Exhaust ventilation system, including supply air valves	+ 20 €/m^2	+ 37 €/m^2
Ventilation system with heat recovery (thermal efficiency 80%)	+ 64 €/m^2	+ 110 €/m^2
Costs savings due to reduced heating power (best standard compared to poorest standard)		
Heat generators		
Gas condensing boiler	- €	- €
Woodpellets boiler	- €	- €
Electrical heat pump (heat source: ground)	-5 €	-10 €
Heat emission system		
Standard radiators	-4 €	-4 €
Underfloor heating	-6 €	-6 €

[12] A detailed description is presented in Annex 1 of the full country report for Germany available at www.bpie.eu

A **residual value** was considered for thermal protection measures (50 years lifetime according to DIN 15459 Annex A). The residual value was determined by a straight-line depreciation of the initial investment costs of the building element to the end of the calculation period (40 % residual value after 30 years) and discounted to the beginning of the calculation period (16.5 % residual value for discount rate 3 %). For windows (30 years lifetime according to DIN 15459 Annex A), neither replacement costs nor a residual value are considered.

Over a 30 year calculation period, **replacement costs** were considered only for technical installations (15 years lifetime) by the use of a replacement factor of 1.64 (3 %discount rate). The lifetime of building elements considered in the calculation is presented in table 20.

Table 20: Lifetime of building elements (according to DIN 15459 Annex A)

Parameter	Lifetime considered in calculation
Thermal insulation	50 years
Windows	30 years
Technical installation	15 years

Annual **maintenance costs** for technical installations were based on the amount of 2 % of the initial investment costs.

Energy costs for heating and hot water were calculated with the results of the energy performance assessment and the assumptions regarding the current energy prices for gas, wood pellets and electricity as well as the assumed energy price development (see table in Annex 4). Energy costs were referred to the living space square meter.

Disposal costs were generally not considered because no reliable data are available. Furthermore, in the case of new buildings, the building lifetime is more than 50 years. In this case, disposal costs are marginal due to discounting (see sensitivity analysis).

However, disposal costs were considered for one reference building and thermal protection measures within the sensitivity analysis performed for additional discount rates and energy prices development for the financial perspective. The disposal costs in this case were assumed as an overall 30 % of the initial investment costs.

Energy price development

Three scenarios of energy price development were considered. Low scenarios (e.g. 1.3 %/a real) are often used in the German national context, including by the Federal Government in the elaboration of energy strategies. The medium scenario (2.8 %/a real) reflects the EU energy price projections to 2030 (EC, 2012b) and was used as baseline scenario for the present study. The high energy prices scenario (4.3 %/a real) assumes a high energy price rise in the future, similar to latest years observed rises (e.g. from 2000 to 2010 there had been a 5 %/yr real increase of energy prices).

In the selection of discount rates and energy price developments, the following effects have to be taken into account:

- Future energy costs per single time period always increase if the assumed energy price development in real terms (inflation adjusted) is higher than 0 %/yr.
- The net present value of energy costs in every single future time period increases more slowly than the energy costs today (period 0) and decreases with increasing time if the discount rate is higher than the assumed energy price development (e.g. discount rate 3 %; energy price development 1 %).
- The net present value of energy costs in every single future time period increases faster than the energy costs today (period 0) and with increasing time if the discount rate is lower than the assumed energy price development (e.g. discount rate 1 %; energy price development 3 %).

Discount rates
From a financial perspective, the discount rate has to reflect the opportunity cost of capital or the expected rate of return. The expected rate of return is market-determined and reflects the riskiness of an investment. It can be split into two components: the risk-free rate of return and a risk premium. The estimation of the discount rate is a complex issue. In economic theory, especially several ways to estimate the risk premium are discussed.

In the German case, inflation-adjusted discount rates of about 3 % (in real terms) are often used for calculations of the energy saving measures profitability in existing and new residential buildings, e.g. in a report about the possible tightening of EnEV 2009 (BMBVS, 2012). These discount rates are often based on current interest rates for long-term mortgages.

A discount rate of 3 % (in real terms) was used as a baseline assumption[13] (IWU, 2012), both for the financial and the macroeconomic perspective. As an alternative, a discount rate 1 % (in real terms) was used for the sensitivity analysis.

Lessons learned

An important influential factor for the cost-optimal methodology is the selection of input factors. The sensitivity analysis showed that the change of one input factor (discount rate, energy price development) has a certain influence on the results compared to the standard assumptions of the basic scenario. Lower discount rates and a higher energy price development lead to lower cost-optimal primary energy values. Therefore, the gap with current requirements becomes bigger and the additional costs of higher energy performance standards compared to EnEV 09 decrease. Higher energy performance standards become more profitable or less 'non-profitable' depending on the standard. The influence on the results is really significant if two input factors are changed simultaneously and take effect in the same direction, e.g. a combination of a 1 % discount rate and a high energy price development. In the frame of the cost-optimal methodology, the choice of input factors has a key influence and should be established with care.

Other important factors for the cost-optimal levels are the initial investment costs. In contrast to existing buildings (Hinz, 2010), empirically verified studies based on invoiced investment costs of energy saving measures for new buildings are currently not available for Germany. The resulting cost data of the procedure mentioned above (IWU, 2012) were analysed and averaged by IWU to determine cost functions, facilitating an easy variation of insulation thickness and building size during the economical assessment.

An alternative method to determine the costs of different energy performance standards would be to undertake a broad market research exercise on new built homes in Germany. The problem is that the energy quality of a building correlates also with other building features. For example, it may be the fact

[13] The 3% discount rate is recommended by the *Cost-Optimality Delegated Regulation* for the macro-economic/societal calculation and it was also agreed and used previously in the framework of IWU (2012) *'Evaluation and Further Development of EnEV 2009: Study about the Economic Framework Conditions in Housing'.*

that energy efficient buildings like passive houses are currently constructed mainly by financially strong owners. Of course, it can be assumed that these owners also install premium bathrooms, kitchens and garages or appreciate prestigious façade surfaces or roof tiles. The incremental costs of insulation could only be determined if the other price determining features were also raised. Such a comprehensive representative survey does not yet exist in Germany. But, even if it could be implemented, the question of accuracy would need to be answered: is the number of new buildings large enough to determine the small influence of the energy performance on the construction costs (or market price), when compared to other features?

6.2.5. Cost-optimal calculation from the financial perspective

Packages of measures with condensing boiler (gas)

The global cost curves for heat supply systems with condensing boiler (gas) are presented in Figure 12. As a reference, the cost value (0 €/m^2) was set for the package of measures of the "BWK+Sol" curve (see below), which satisfies both current requirements of EnEV 2009 and EEWärmeG 2009.

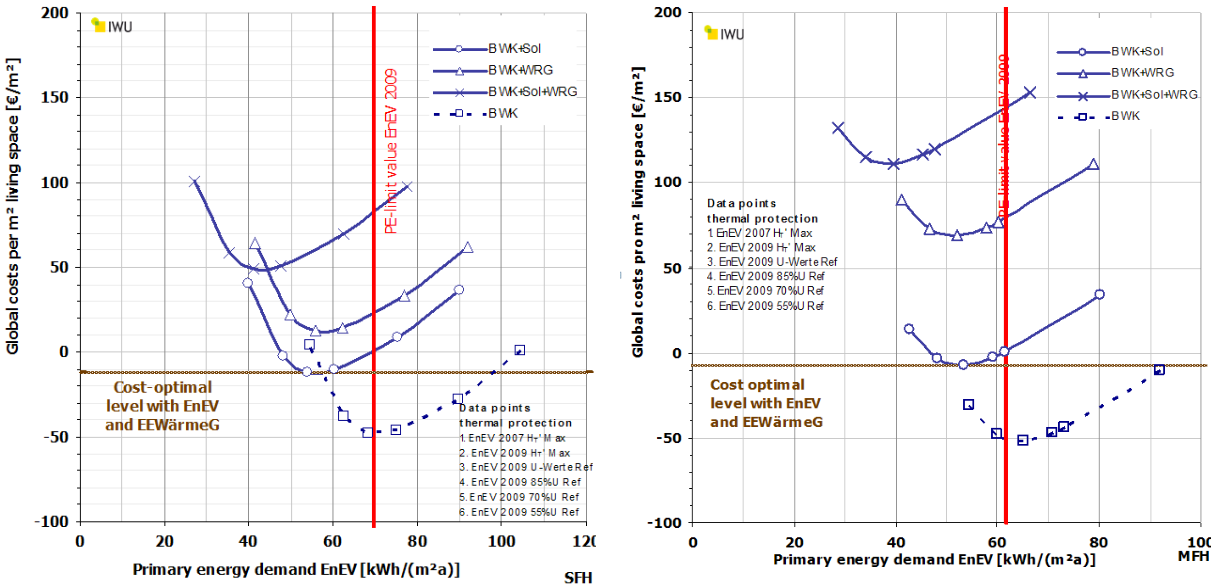
The whole curve "BWK" (i.e. packages of measures comprising combinations between thermal insulation variants and condensing boiler) is not in line with the actual minimum requirements in Germany for new buildings – particularly with the renewable energies and heat law (EEWärmeG) (see explanations below).

The vertical red line marks the accepted primary energy demand according to EnEV 2009 (main requirement – for the SFH approx. 70 kWh/m^{2}yr). Furthermore, a requirement concerning the thermal protection of the building also has to be considered (additional requirement marked by the second data point of the curves). As a result, all intersections of the global costs curves with the vertical red line mark the legal minimum energy performance requirements if the second data point of the curves is on the right end of the red line. In these cases, the main and additional requirements of the EnEV 2009 are fulfilled.

If the second data point of the curves is on the left end of the red line e.g. in the case of the upper curve – "BWK+Sol+WRG" the vertical red line is not the minimum energy performance requirement because the additional requirement concerning the thermal protection is not fulfilled. In this case, the second data point marks the minimum energy performance requirements (approx. 63 kWh/m^{2}yr primary energy demand).

The *Renewable Energy Ordinance EEWärmeG* was introduced at the beginning of 2009. It defines the use of renewable energies or comparable efficient technologies for new buildings. According to EEWärmeG, if renewable or comparable efficient systems are not installed in the building, a 15 % reduction in the primary energy limit of EnEV 2009 is required (in the case of SFH with condensing boiler, a primary energy demand of approx. 60 kWh/m^{2}yr has to be reached by improved thermal insulation). For the SFH with condensing boiler ("BWK"), the requirements of both EnEV and EEWärmeG are fulfilled only by the most advanced thermal insulation variant at global costs comparable to packages of measures from "BWK+Sol" curve. In the case of the MFH, the requirements of EnEV and EEWärmeG (primary energy demand 15 % lower than approximately 61 kWh/m^{2}yr) cannot be fulfilled without solar heating system, even with the best thermal insulation variants. Consequently, in the following figures, the "BWK+Sol" curve represents the most economic packages of measures, satisfying both EnEV 09 and EEWärmeG.

Figure 12 : Global costs in SFH and MFH for heat supply systems with condensing gas boiler (baseline scenario, medium energy price development)



Packages of measures with all heat supply systems

Figure 13 shows the global costs per living space square meter versus the primary energy demand for the SFH and the MFH for all heat supply systems (medium energy price development).

The calculations results are summarised in the following:

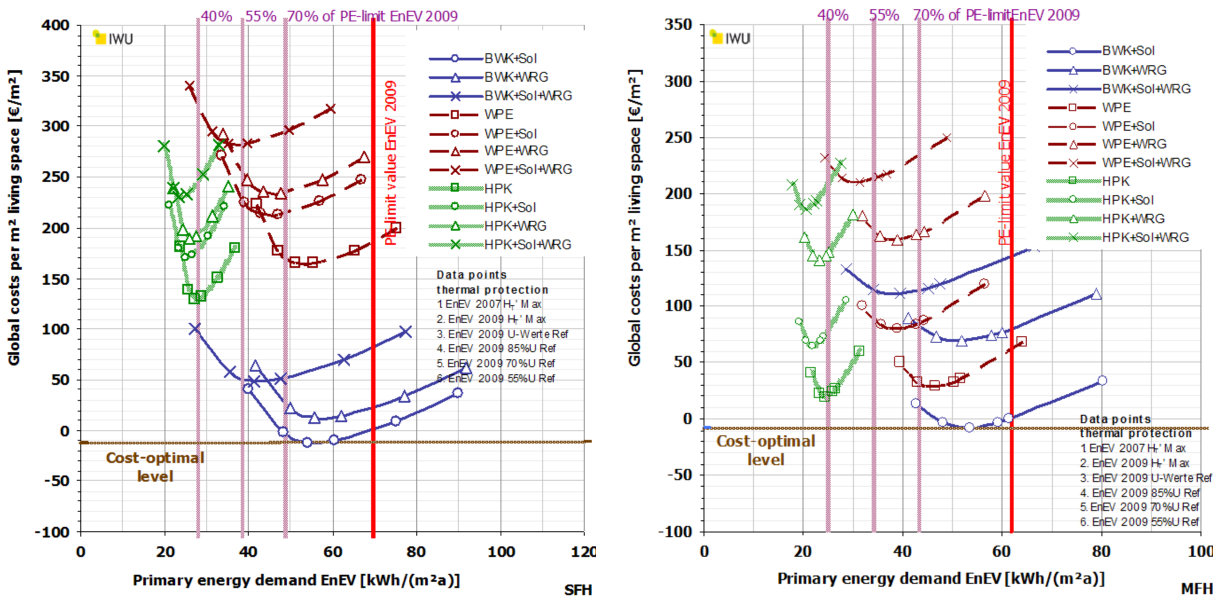
- The cost-optimal level for both SFH and MFH is represented by a package composed by thermal insulation standard with U-values at 85% of the EnEV 2009 for reference building, combined with a condensing boiler and with solar heating system (4th data point of the curve – BWK+Sol / primary demand approx. 53-54 kWh/m^{2}yr).
- The minimum energy performance requirements could be tightened by about 13% (MFH) and 23% (SFH) to achieve cost-optimal levels (Table 21) and by about 25 % (MFH) to 30 % (SFH) in order to achieve the same global costs than EnEV 2009.

Table 21 : Comparison table for new buildings (financial perspective)

Reference building	Cost-optimal level	Current requirements (EnEV 09)	Gap	
	[kwh/m^{2}yr]	[kwh/m^{2}yr]	[kwh/m^{2}yr]	[%]
SFH	54	70	16	23%
MFH	53	61	8	13%)

- Packages based on combinations of thermal insulation measures with wood pellet boilers or electric heat pumps have nearly comparable global costs for both SFH and MFH. The global costs are nevertheless higher than those of packages including condensing boilers, but the primary energy demand values are lower, especially for heat supply systems with wood pellet boilers. The global costs differences are more significant for the SFH than in the MFH (due to lower investment costs per sq. meter for wood pellet boilers and electric heat pumps in the MFH).
- The current minimum energy performance requirements of EnEV 2009 for new buildings do not yet achieve the cost-optimal levels. Compared to EnEV 2009, the cost-optimal levels lead to decreases of the global costs by about 12 €/m² (SFH) and 8 €/m² (MFH).

Figure 13 : Global costs for SFH and MFH for all heat supply systems (baseline scenario, medium energy price development)



Energy performance standards towards nZEB

As mentioned above, the Efficiency Building 40 (EB 40) was currently used as a widely agreed equivalent of a possible nZEB standard. As possible step towards "nearly Zero-Energy Buildings (nZEB)", the Efficiency Buildings 55 (EB 55) was also discussed for both reference buildings[14]. In the following paragraphs, only the results for EB 40 are presented.

For the reference building SFH (Figure 13, left part), EB 40 can be identified as follows:

- Primary energy demand of at least 40 % of the requirements of EnEV 2009 and thermal protection standard: 55% of "EnEV 2009 U Ref". This standard is achieved only by the 6thdata points of the curves "BWK+Sol+WRG", "WPE+Sol+WRG", "HPK", "HPK-Sol", "HPK+WRG", "HPK+Sol+WRG".

[14] See the full country report for Germany available at www.bpie.eu

In the following paragraph, the additional costs of advanced energy performance standards towards nearly zero-energy levels compared to the current requirements of EnEV 09 will be identified. Among the possible variants mentioned above, only the most cost-effective combinations of thermal protection standard and heat supply system are presented.

The additional costs are calculated as difference costs between the global costs for the better energy performance standards and the global costs for EnEV 09:

- Reference building SFH: the energy performance standard „Efficiency Building 40" can be achieved in the most cost-effective way by a combination of ambitious thermal protection measures, as well as a condensing boiler with solar heating and ventilation systems with heat recovery (6th data point of the curve "BWK+Sol+WRG"). The additional global costs compared to EnEV 09 are 101 €/m² in this case.
- Reference building MFH: the energy performance standard „Efficiency Building 40" can be achieved in the most cost-effective way by a combination of ambitious thermal protection measures and a wood pellet boiler (6th data point of the curve "HPK"). The additional global costs compared to EnEV 09 are 41 €/m² in this case.

Table 22: Increases of global costs towards nZEB compared to EnEV 09 (medium energy price development)

Reference building	"Cost-optimal level" to EnEV 09	"Efficiency Building 55" to EnEV 09	"Efficiency Building 40" to EnEV 09	
SFH	-12 €/m²	58 €/m²	101 €/m²	23%
MFH	-8 €/m²	23 €/m²	41 €/m²	13%

Compared to typical construction costs for new buildings in Germany (1300 €/m²), the global costs for the most cost-effective standards towards nZEB range between additional 2 - 8 % compared to EnEV 09. These percentages are in a similar range as "typical fluctuations" of construction costs. Nevertheless, a tightening of the minimum energy performance requirements from EnEV 09 or the cost-optimal level[15] towards nZEB would be non-economical (higher global costs). This is in line with the EPBD, but would cause problems with the German energy saving law (EnEG), which stipulates that minimum energy performance requirements have to be "economically justifiable". This may turn out to be an obstacle for the implementation of the EPBD requirements to introduce nZEB levels for new buildings in 2020. After the planned tightening of requirements (the maximum primary energy demand shall be lowered in two steps, each by 12.5%), further improvements will be non-economical and therefore not justifiable with respect to the German energy saving law.

6.2.6. Macroeconomic perspective

Following the *Cost-Optimality Delegated Regulation* (EC, 2012a), the European Member States have to calculate the cost-optimal level both from a financial and a macroeconomic perspective. After the calculation, Member States have to settle on one of these.

The following calculations from a macroeconomic perspective were done for the basic scenario (discount rate 3%; medium energy price development). Compared to the main assumptions of the financial perspective the following changes for the calculations were made:

- All cost categories did not include VAT (19 %),
- Cost of greenhouse gas emissions were considered additionally.

[15] The global costs of nZEB standards compared to the cost-optimal level are about 12 €/m² (SFH) and 8 €/m² (MFH) higher than in Table 22.

To calculate the greenhouse gas emissions from the final energy values, the following CO_2-factors (IWU, 2009) were used:

- Gas: 242 [g/kWhEnd]
- Wood pellets: 41 [g/kWhEnd]
- Electricity: 633 [g/kWhEnd]

The costs of CO_2 emissions for the years of the calculation period are based on the carbon prices from Annex II of the *Cost-Optimality Delegated Regulation* (EC, 2012a) such as: EUR 20 /t CO_2 until 2025, EUR 35/t CO_2 until 2030 and EUR 50/t CO_2 beyond 2030. The resulting cost of CO_2 emissions per year is discounted with respect to the beginning of the calculation period (net present value method).

Figure 14 : Global costs for SFH and MFH for all heat supply systems (macroeconomic perspective; medium energy price development)

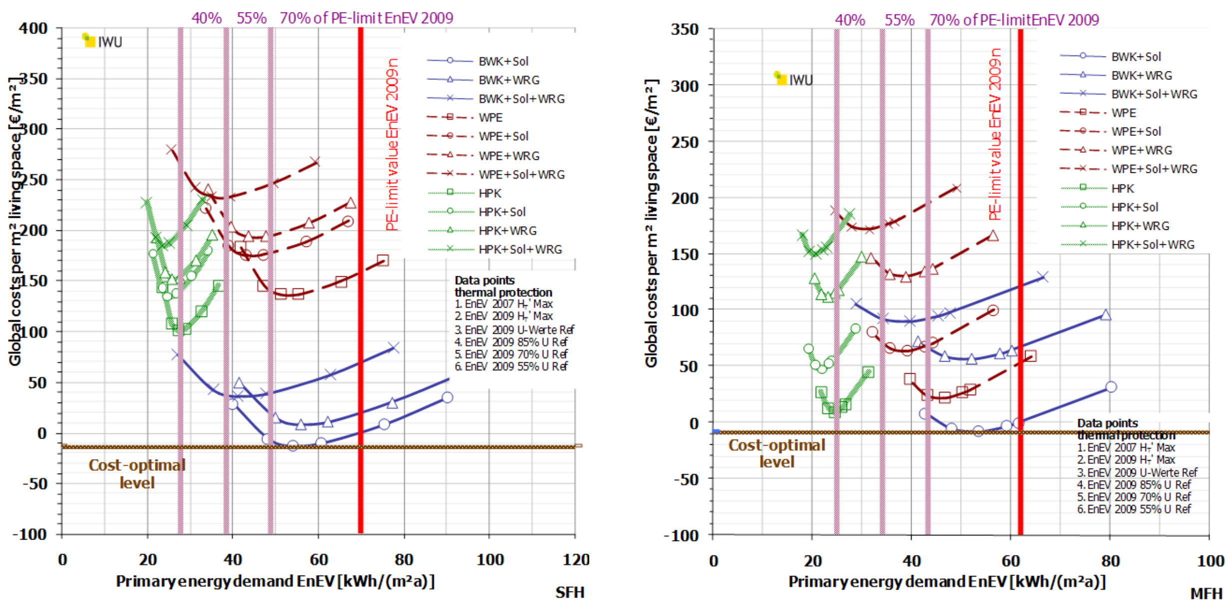


Figure 14 shows that the cost-optimal levels do not change compared to the financial perspective (cost-optimal level 54 kWh/(m^{2}a) for SFH and 53 kWh/(m^{2}a) for MFH). The assumed carbon prices from Annex II of the *Cost-Optimality Delegated Regulation* were too low to influence the cost-optimal levels significantly.

Only the additional costs of advanced energy performance standards compared to EnEV 09 decrease from a macro-economic perspective.

Table 23 : Increases of global costs towards nZEB compared to EnEV 09 (macroeconomic perspective)

Reference building	"Cost-optimal level" to EnEV 09	"Efficiency Building 55" to EnEV 09	"Efficiency Building 40" to EnEV 09	
SFH	-13 €/m^2	43 €/m^2	77 €/m^2	23%
MFH	-8 €/m^2	13 €/m^2	27 €/m^2	13%

In the case of SFH, the additional global costs of EB 40 compared to EnEV 09 decrease to 77 €/m^2 (6th data point of the curve "BWK+Sol+WRG"). The additional global costs of EB 40 in the case of MFH decrease to 27 €/m^2 (6th data point of the curve "HPK").

6.2.7. Sensitivity analysis

A sensitivity analysis was performed on exemplary discount rates and the energy performance development from the financial perspective. The results of the sensitivity analysis in terms of cost-optimal levels and the additional costs of energy performance standards towards nZEB are presented in the followings[16]. A cost-optimal range is presented if the cost differences between two "cost-optimal levels" are inferior to 1 €/m². The most cost-effective variants towards nZEB do not change compared to the basic scenario.

Discount rate variation

Using a lower discount rate results in increased future cost categories as well as an increase of the residual value; taken into consideration the NPV calculation compared to the basic scenario. Overall, for a discount rate of 1 %, the global costs increased but the cost-optimal levels moved towards lower primary energy levels. Therefore, the gap to current requirements of EnEV 09 becomes bigger and higher energy performance standards become more profitable or 'less non-profitable', depending on the package of measures.

The results of the sensitivity analysis with a discount rate of 1 % are presented in Tables 24 and 25.

Table 24: Results of sensitivity analysis for discount rate variation for SFH and MFH at medium energy price development)

		SFH		MFH	
DISCOUNT RATE		1 %	3 % (basic scenario)	1 %	3 % (basic scenario)
Cost-optimal level	[kWh/m²yr]	48-54	54	48	53
Gap to EnEV 09	[kWh/m²yr]	16-22	16	13	8
	[%]	23%-31%	23%	21%	13%
Additional costs CO to EnEV 09	[€/m²]	-31	-12	-20	-8
Additional costs EB 55 to EnEV 09	[€/m²]	+34	+58	+18	+23
Additional costs EB 40 to EnEV 09	[€/m²]	+59	+101	+26	+41

For the SFH, the cost-optimal level is now described both at the 4th data point of the curve "BWK+Sol" and the 5th data point of the curve "BWK+Sol" (cost-optimal range from 48-54 kWh/m²yr); the 4th data point (54 kWh/m²yr) has minimal lower global costs inferior to 1 €/m²)). The additional costs of better energy performance standards (EB 55, EB 40) decrease compared to EnEV 09[17].

For the MFH, the cost-optimal level moves from the 4th data point of the curve "BWK+Sol" to the 5th data point of the curve "BWK+Sol" (cost-optimal level 48 kWh/(m²a)). The additional costs of better energy performance standards (EB 55, EB 40) also decrease compared to EnEV 09[18].

[16] For detailed figures see Annex 4 from full country report for Germany available at www.bpie.eu
[17] For detailed figures see Annex 3 and 4 from full country report for Germany available at www.bpie.eu
[18] For detailed figures see Annex 3 and 4 from full country report for Germany available at www.bpie.eu

Energy price development variation

Beside the basic scenario (2.8 %/yr), two further scenarios of energy price development are considered[19].

A high energy price development (4.3 %/yr) means that the net present value of future energy costs increase compared to the basic scenario, but the cost-optimal levels move in direction of lower primary energy values, the gap to current requirements of EnEV 09 becomes bigger and the additional costs of higher energy performance standards compared to EnEV 09 decrease (higher energy performance standards are becoming more profitable or 'less non-profitable' depending on the standard).

A low energy price development (1.3 %/yr) means that the net present value of future energy costs decreases compared to the basic scenario, but the cost-optimal levels move in direction of higher primary energy values, the gap to current requirements of EnEV 09 becomes smaller and the additional costs of higher energy performance standards compared to EnEV 09 increase (higher energy performance standards are becoming less profitable or 'more non-profitable' depending on the standard).

The results for SFH and MFH are shown in Table 25.

Table 25: Results of sensitivity analysis energy price development for SFH and MFH at fixed discount rate of 3%

		SFH			MFH		
DISCOUNT RATE		**1.3 %**	**2.8 %** (basic scenario)	**4.3 %**	**1.3 %**	**3 %** (basic scenario)	**4.3 %**
Cost-optimal level	[kWh/m²yr]	60	54	54	53	53	48-53
Gap to EnEV 09	[kWh/m²yr]	10	16	16	8	8	8-13
	[%]	14%	23%	23%	13%	13%	13%-21%
Additional costs CO to EnEV 09	[€/m²]	-2	-12	-22	-4	-8	-12
Additional costs EB 55 to EnEV 09	[€/m²]	+81	+58	+37	+22	+23	+24
Additional costs EB 40 to EnEV 09	[€/m²]	+127	+101	+74	+42	+41	+39

High energy price development SFH: the cost-optimal level is still described by the 4th data point of the curve "BWK+Sol" (cost-optimal level 54 kWh/m²yr). The additional costs of better energy performance standards (EB 55, EB 40) are decreasing compared to the basic scenario.

Low energy price development SFH: the cost-optimal level moves to the 3rd data point of the curve "BWK+Sol" (cost-optimal level 60 kWh/m²yr). The additional costs of better energy performance standards (EB 55, EB 40) are increasing compared to the basic scenario.

High energy price development MFH: the cost-optimal level is described now both at the 4th data point of the curve "BWK+Sol" and the 5th data point of the curve "BWK+Sol" (cost-optimal range from 48-53 kWh/m²yr; the 4th data point has minimal lower global costs < 1 €/m²). The additional costs of better energy performance standards stay nearly constant (EB 55) or are decreasing (EB 40) compared to the basic scenario.

Low energy price development MFH: the cost-optimal level is described still by the 4th data point of the curve "BWK+Sol" (cost-optimal level 53 kWh/m²yr). The additional costs of better energy performance standards stay nearly constant (EB 55) or are increasing (EB 40) compared to the basic scenario.

[19] For detailed figures see Annex 4 from full country report for Germany available at www.bpie.eu

Due to actual lower energy prices for wood pellets and relatively high energy use for heating and hot water, the effect of a low energy price development on the additional costs is less obvious for the variants with wood pellet boiler in the MFH (EB 55 and 40). In the case of EB 55 the net present value of energy costs is even decreasing more than for the variant EnEV 09 (with gas condensing boiler and solar heating system).

Discount rate 1 % in real terms and high energy price development
An additional variation of input parameters was carried out for the SFH reference building, for a high energy price development scenario and a low discount rate of 1 %. The results are shown in Figure 15[20]. The changes are obvious especially for the heat supply systems with a condensing boiler. The cost-optimal primary energy demand moves to approx. 48 kWh/m²yr and the additional costs from EnEV 09 to nZEB level decrease, e.g. for Efficiency Building 40 from 101 €/m² to 19 €/m² (see table 26).

Compared to the current minimum energy performance requirements of EnEV 2009 (intersection of the red vertical line with the curve "BWK+Sol"), the energy performance standard Efficiency Building 55 (5th data point of the curve "BWK+Sol+WRG) could now be reached with nearly the same global costs.

Figure 15: Global costs for SFH / all heat supply systems (high energy price development/discount rate 1 %)

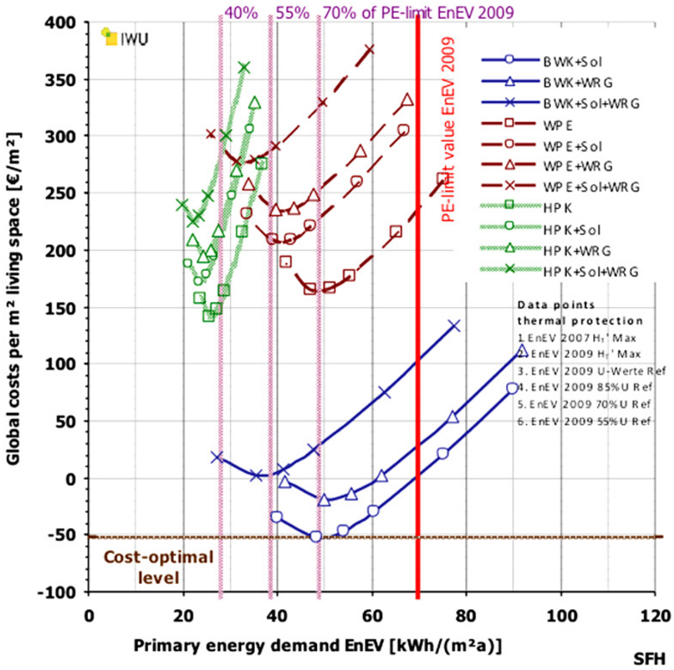


Table 26 : Results of sensitivity analysis for SFH (high energy price development; low discount rate)

ENERGY PRICE DEVELOPMENT / DISCOUNT RATE		4.3 % (REAL) / 1 %	2.8 % (REAL) / 3 % (BASIC SCENARIO)
Cost-optimal level	[kWh/m²yr]	48	54
Gap to EnEV 09	[kWh/m²yr]	22	16
	[%]	31%	23%
Additional costs CO to EnEV 09	[€/m²]	-52	-12
Additional costs EB 55 to EnEV 09	[€/m²]	+2	+58
Additional costs EB 40 to EnEV 09	[€/m²]	+19	+101

[20] For detailed figures see in Annex 4 from full country report for Germany available at www.bpie.eu

Furthermore, disposal costs were considered for one reference building and thermal protection measures. The disposal costs at the end of the lifetime (50 years) were assumed as an overall percentage (30 %) of the initial investment costs. Discounted to the end of the calculation period, the disposal costs reduce the residual value of the insulation measures about 17 %. As a result, the global costs increase marginally and the cost-optimum moves slightly to the right. Due to discounting, the influence of future disposal costs on the cost-optimal level remains marginal.

6.3. COST-OPTIMAL CALCULATION FOR POLAND

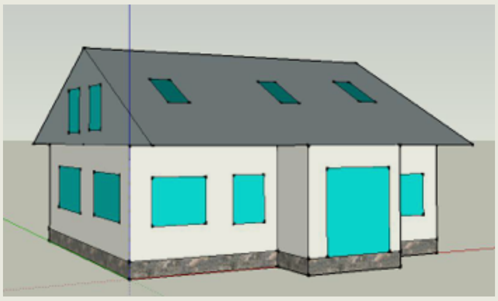
A full version of the cost-optimal calculation study for Poland can be found on the BPIE website www.bpie.eu, while the main findings are presented in this section.

6.3.1. Reference buildings

There are no official definitions of reference buildings in Poland, not even for single family houses (SFH). For the purpose of this report, a reference building was established based on the BuildDesk database, which consists of data for around 50 000 SFH from energy performance assessment calculations. The selected reference building for a single family house corresponds to a typical design of SFH in Poland.

The parameters of the reference building related to its energy efficiency reflect the current Polish requirements for new buildings. Those parameters were assumed as the base scenario in the analysis of all energy efficiency packages.

Table 27: Characteristics of single family house-reference building

Building's characteristics	Single-family building (SFH)
Building sketch	
Building geometry	0.8 [1/m]
Heated living space (Af)	171.2 m^2
Heated volume (Ve)	433.35m^3
Area of building envelope (according to external dimensions)	427.5m^2
Typical energy performance (primary energy demand per m^2 of Af)	124 [kWh/(a m^2)]
Energy performance of elements (current requirements)	Walls: U = 0.30 [W/(m^2K)] Floor: U = 0.45 [W/(m^2K)] Roof: U = 0.25 [W/(m^2K)]

Lessons learned

For the purpose of this study, one of the many typical "ready-to-use" designs of SFH was chosen as reference SFH building. Input on how to choose and establish reference SFH came from the BuildDesk database. One of the crucial issues was to establish the energy performance of different elements, e.g. the envelope parameters. Data derived from BuildDesk database reveal that the average U-values for new SFH are only slightly better than those existing as requirements. For instance, the average U-value for walls in new SFH is around 0.29 W/(m^2K) compared to required U = 0.30 W/(m^2K). The situation is better in the case of windows, since the required value of U is 1.8 W/(m^2K) and, actually, the windows, mostly used in SFH, have a U-value ranging between 1.5 and 1.3 W/(m^2K). Considering all this, it was decided to use, for opaque elements, a reference U-value according to current requirements, and for windows to use U = 1.5 and g = 0.67 (double glazing with low – emission layer).

6.3.2. Selection of variants for thermal insulation and equipment

For the purpose of this study, 680 scenarios were computed (taking into account the energy price development, discount rates, climate data and set of measures). Energy efficiency measures were divided into four main groups:

- Improvements of envelope,
- Windows,
- Mechanical ventilation with heat recovery,
- And solar collectors.

For the improvements of opaque envelopes, five different packages were prepared, starting from current requirements, Variant 1 (en_1), and finishing with the Variant 5 (en_5). The last set of measures (en_5) reflects requirements according to the new supporting scheme for low energy SHF owners, provided by the National Found of Environmental Protection and Water Management. Those requirements (en_5) are compulsory for SFH, according to the NF40 standard, and require no more than 40 kWh/(m^2 a) as energy need for heating. The packages en_2, en_3 and en_4 were chosen as intermediates ones. For all considered variants, the same thermal bridging influence (22 [W/K]) was assumed as a constant addition to the heat transfer coefficient (Htr).

Improvements of opaque elements ("en")

For energy efficiency measures related to the buildings envelope, four different packages (en_2, en_3, en_4, en_5) of further insulation added to external walls, roof and floor were assumed. All these five variants were calculated in the five considered locations, considering also the two most popular energy carriers in Poland (coal and natural gas) and four energy price development scenarios. The reason for such an extended analysis was to present the optimal U values for opaque elements in different climatic zones in Poland. An analysis of other components and elements (i.e. windows, solar collectors, mechanical ventilations, heat supply systems) was performed only for Warsaw, which reflects climatic conditions for the third and biggest climatic zone in Poland.

Windows and their properties (i.e. thermal transmittance - U, solar energy transmittance - g) were analysed separately.

Table 28: Set of energy efficiency measures related to the building envelope

Building Envelope	Variant 1 - en_1 (Reference case)	Variant 2 - en_2	Variant 3 - en_3	Variant 4 - en_4	Variant 5 - en_5
	U [W/(m²K)]	U [W/(m²K)]	U [W/(m²K)]	U [W/(m2K)]	U [W/(m²K)]
Walls	0.30	0.26	0.22	0.18	0.15
Roof	0.25	0.2	0.16	0.12	0.1
Floor	0.45	0.35	0.30	0.25	0.20
Windows	U= 1.5; g=0.67	U= 1.5; g=0.67	U= 1.5; g=0.67	U= 1.5; g=0.67	U= 1.5; g=0.67

The next step in identifying optimal energy efficiency solutions involved the windows and their impact on the energy performance. For this purpose, five different scenarios were assumed. The optimization of windows was carried out by using climate data from Warsaw.

Table 29: U and g values variants for windows

Windows	w_1	w_2	w_3	w_4	w_5
U [W/(m²K)]	1.5	1.3	1.1	0.9	0.8
g [-]	0.67	0.67	0.5	0.5	0.5

Undoubtedly, it is more difficult to assess the influence of windows on the building's energy performance than the influence of the opaque envelope. Windows have many parameters related to energy efficiency (e.g. thermal transmittance, solar radiation transmittance and infiltration of air). Apart from parameters directly associated with windows, there are also global building characteristics such as heat capacity building zones, heat transfer coefficients through ventilation, external envelope as well as others. Windows can also be optimized and classified regarding cooling demand or/and heating demand of buildings.

For the purpose of this study, different window solutions (according to Table 3) were assessed, considering two kind of building envelopes: en_1 and en_5.

Table 30: Considered variants with different windows solutions

	w_1	w_2	w_3	w_4	w_5
Building envelope	en_1	en_1	en_1	en_1	en_1
	en_5	en_5	en_5	en_5	en_5

Mechanical ventilation with heat recovery and solar collectors
The following types of energy efficiency improvements were taken into account:

- Mechanical ventilation with 75% heat recovery efficiency (signed as "mv")
- Solar collector installation in DHW system with 50% coverage of DHW heating (signed as "s")

The use of mechanical ventilation and of solar collectors were analysed separately from the external envelope basic variants (en_1).

Table 31: Considered variants with mechanical ventilation and solar collectors

Windows	Mechanical ventilation	Solar collectors
Building envelope	en_1	en_1
	0.67	0.67

Packages of measures at nearly zero-energy levels
Poland has not yet announced (as of February 2013) an official nZEB definition. Nevertheless, the Ministry of Transport, Construction and Maritime Economy has officially announced a proposal of requirements regarding the buildings energy efficiency. This proposal, apart from new requirements for U and EP values, also includes a plan for the 2014, 2017 and 2021 requirements. For SFH, it was proposed to establish EP = 70 kWh/(m^2 a) from 2021 and beyond, and, hence, it can be assumed that a nZEB definition will be close to that value of primary energy demand per square meter of heated area.

For the purpose of a possible nZEB definition, optimal packages of external envelope (en_4 or en_5 and w_2), mechanical ventilation system with heat recovery and optionally solar collectors were chosen.

Table 32: Considered sets of nZEB measures

	1	2	3	4
nZEBs set of measures	en_4 + w_2 + mv	en_4 + w_2 + mv + s	en_5 + w_2 + mv	en_5 + w_2 + mv + s

6.3.3. Primary energy demand calculation

Calculation procedure
For all variants, the energy need for heating was calculated using the monthly method according to PN – EN ISO 13790: 2009 standard. The efficiency of the heating and DHW systems and the primary energy demand was based on the national methodology for assessing the energy characteristics of buildings.

Energy scope considered in the cost-optimal calculation
For the calculation of the primary energy demand, the energy used for heating, cooling, domestic hot water, ventilation, internal lighting and other auxiliary systems were considered.

Conversion factors for primary energy
The primary energy conversion factors used for Poland's case study:

Coal:	1.1;
Natural gas:	1.1;
Heating oil:	1.1;
Electricity:	3.0;
Wood pellets (biomass):	0.2;
Solar collectors:	0.0.

6.3.4. Global cost calculation

Basic assumptions

The cost-optimal calculation was performed over a 30-year period, as requested by the *Cost-Optimality Delegated Regulation*.

Energy price development

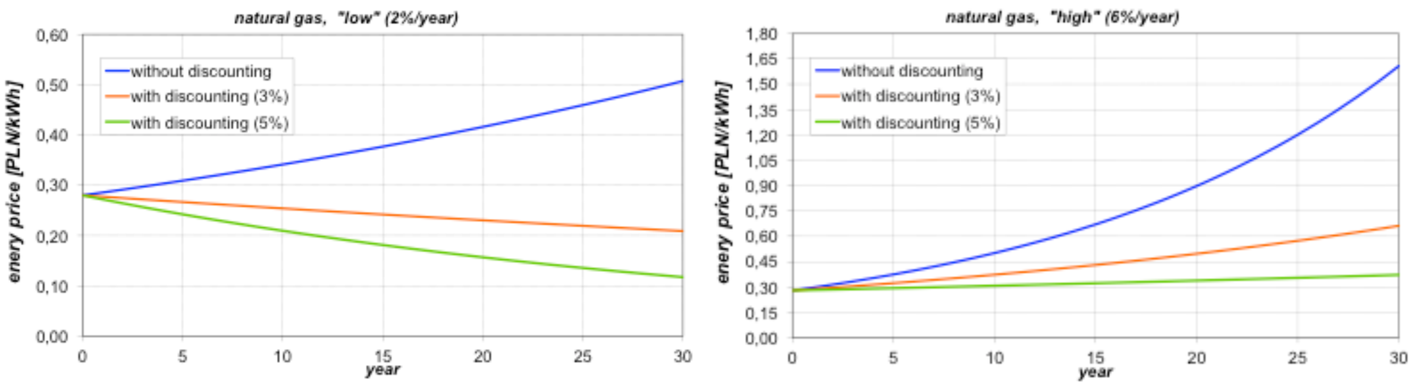
The current energy prices assumed in the analysis were:

- Natural gas: 0.28 PLN/kWh (0.07 €/kWh).
- Coal: 0.13 PLN/kWh (0.03 €/kWh).
- Heating oil: 0.34 PLN/kWh (0.08 €/kWh).
- Electricity: 0.55 PLN/kWh (0.13 €/kWh).
- Wood pellets: 0.18 PLN/kWh (0.04 €/kWh).

Main heating sources in SFH are coal and natural gas.

Below, two different scenarios (low, high) of energy price development are presented, based on natural gas. For each scenario, two different discount rates were assumed.

Figure 16: Assumed scenarios of energy price development



Energy prices development scenarios were described as: x%/y%. The first number (x) symbolises the increasing rate of energy price year by year. The second number (y) symbolises the discount rate. Describing these scenarios more literally (see graphs above), we can say that:

- 2%/5% means faster decrease of the real cost of the energy carrier,
- 2%/3% means slower decrease of the real cost of the energy carrier,
- 6%/5% means slower increase of the real cost of the energy carrier,
- 6%/3% means faster increase of the real cost of the energy carrier (base scenario).

Discount rates

A discount rate of 3% was used as a base scenario, which is currently a reliable assumption for Poland. For the sensitivity analysis, a discount rate of 5% was assumed because of the high inflation rate Poland is witnessing since the last couple of years.

Input parameters

As for the maintenance costs: heating costs, DHW and cost of electricity consumed by auxiliary equipment, e.g. fans, circulation and distribution pumps were included in the scope.

Table 33: Specific costs of increased thermal protection comparing to basic variant: en_1

		en_2	en_3	en_4	en_5
Outer wall		**U = 0.26**	**U = 0.22**	**U = 0.18**	**U = 0.15**
	[€/m^2]	1.62	3.83	7.62	12.63
	[€/cm/m^2]	0.85	0.85	0.93	1.02
Roof		**U = 0.22**	**U = 0.16**	**U = 0.12**	**U = 0.1**
	[€/m^2]	0.51	2.50	6.02	11.12
	[€/cm/m^2]	0.24	0.29	0.37	0.49
Floor		**U = 0.35**	**U = 0.30**	**U = 0.25**	**U = 0.20**
	[€/m^2]	1.58	2.53	4.02	6.46
	[€/cm/m^2]	0.37	0.37	0.37	0.37

Table 34: Specific costs of windows comparing to basic variant: w_1

		en_2	en_3	en_4	en_5
Windows		**U = 1.3; g = 0.67**	**U = 1.1; g = 0.5**	**U = 0.9; g = 0.5**	**U = 0.8; g = 0.5**
	[€/m^2]	24.4	24.4	48.8	73.2

Table 35: Cost of mechanical ventilation system with heat recovery ("mv") and solar collector system ("s")

		mv	s
Systems	[€]	3 659	2 927

Climate data input

Five different climatic zones and relevant data were considered in the study. Further details can be found in the full cost-optimality case study for Poland available at www.bpie.eu.

Lessons learned

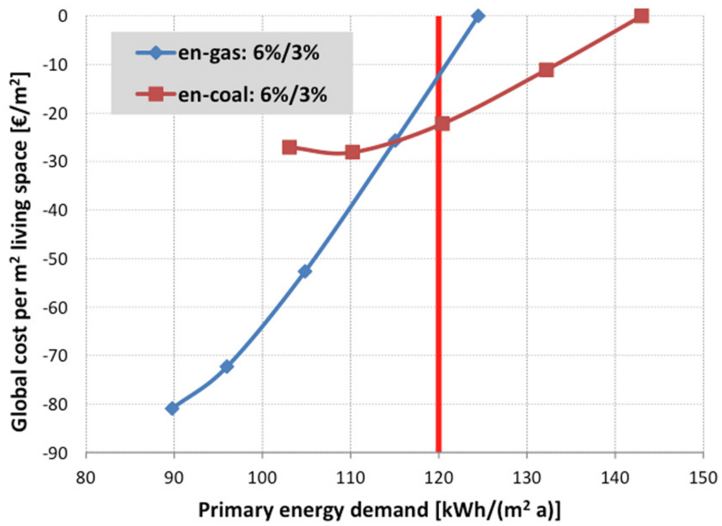
The basic discount rate (3%) was chosen based on the current real capital cost in Poland. A higher discount rate of 5% was chosen to show that even with a lower value of global costs there is still a big gap between the current requirements regarding buildings energy efficiency and those indicated as optimal.

6.3.5. Cost-optimal calculation from the financial perspective

Packages of measures with condensing boiler (gas)

The global cost curves for heat supply systems with gas (condensing boiler) and coal are presented in Figure 16. Those two types of energy carriers are most popular among single family house owners. As a reference, the value of global costs of 0 €/m^2 was defined for new SFH with a thermal protection according to current requirements. Figures show the results obtained for the basic ("6%/3%") energy prices development scenarios: 6% - annual rate of energy price increase; 3% - discount rate. As the calculation revealed, the optimal packages of measures are: en_4 (in the case of coal) and en_5 (in the case of gas).

Figure 16: Global costs for gas and coal supply systems (6% energy price development, 3% discount rate) for "en" packages



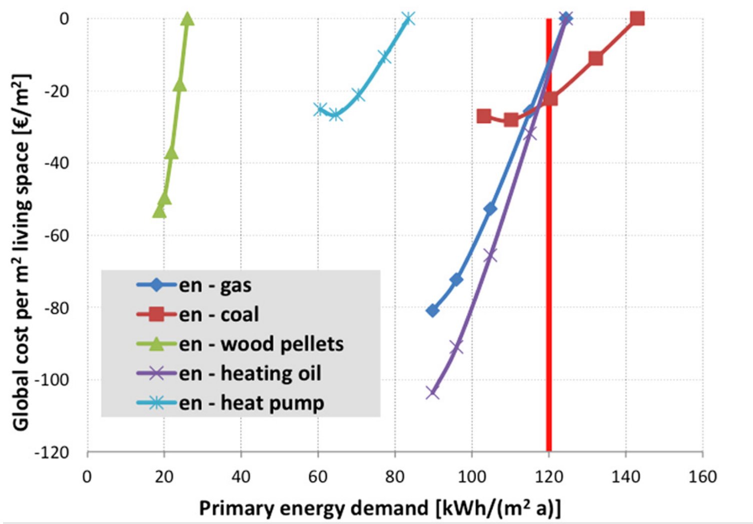
Currently, the usage of RES is not mandatory for new buildings in Poland. Therefore, solar collectors were considered as an improvement variant.

Table 36: The comparison of optimal U levels with current requirements

Building's Element	Current requirements	Cost–optimal level	Gap	
	[W/m²K]	[W/m²K]	[W/m²K]	[%]
External wall	0.30	0.18 (coal); 0.15 (gas)	0.12 (coal); 0.15 (gas)	40% (coal); 50% (gas);
Floor	0.45	0.25 (coal); 0.20 (gas)	0.20 (coal); 0.25 (gas)	44% (coal); 56% (gas);
Roofs	0.25	0.12 (coal); 0.10 (gas)	0.13 (coal); 0.15 (gas)	52% (coal); 60% (gas);

Packages of measures with all heat supply systems

Figure 17: Global costs for all supply systems (6% energy price development, 3% discount rate) for "en" packages



The obtained results revealed optimal envelope packages. The red line in Figure 17 shows the primary energy demand (120 kWh/(m^2 a)) which will be required from 2014 for SFH, according to the last official proposal of regulations regarding buildings energy efficiency.

Energy performance standards towards nZEB

As the performed calculation revealed, the most cost–optimal solutions towards achieving nZEB standards are measures related to the improvement of the external envelope, especially if we compare optimal U values with current requirements. Other possible improvement steps could be mechanical ventilation with heat recovery and solar collectors.

6.3.6. Macroeconomic perspective and sensitivity analysis

The following calculations from a macroeconomic perspective are done for 6%/3%, 6%/5% and 2%/3% scenarios for gas and coal as energy carriers. The macroeconomic approach has been performed only for external envelope improvements (so called "en" packages).

To calculate the costs of greenhouse gas emissions for the single years of the calculation period, the carbon prices from Annex II of the *Cost-Optimality Delegated Regulation* are used , i.e. EUR 20 /t CO_2 until 2025, EUR 35/ t CO_2 until 2030 and EUR 50/ t CO_2 beyond 2030. The resulting cost of greenhouse gas emissions per year was discounted to the beginning of the calculation period (net present value method).

Figure 18: Global costs for gas (left figure) and coal (right figure) heat supply systems (macroeconomic perspective – dashed line; financial perspective - solid line).

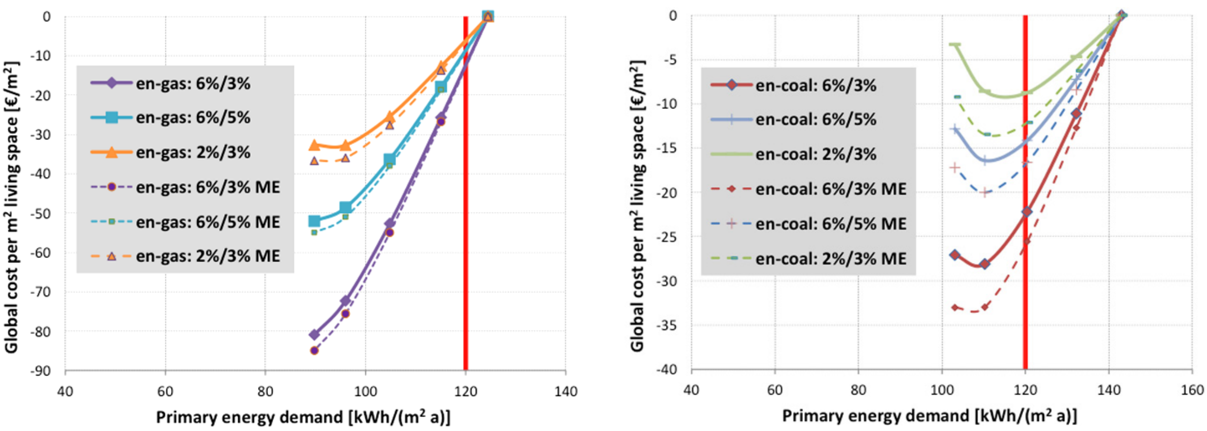


Figure 18 shows that the cost-optimal levels do not change optimal packages compared to the financial perspective. The considered cost of greenhouse gas emissions regarding the assumed carbon prices from Annex II of the Cost-Optimality Delegated Regulation are too low to influence significantly cost-optimal levels.

Table 37: The comparison of optimal U levels with current requirements

Building's Element	Current requirements	Cost–optimal level	Gap	
	[W/m²K]	[W/m²K]	[W/m²K]	[%]
External wall	0.30	0.18 (coal); 0.15 (gas)	0.12 (coal); 0.15 (gas)	40% (coal); 50% (gas);
Floor	0.45	0.25 (coal); 0.20 (gas)	0.20 (coal); 0.25 (gas)	44% (coal); 56% (gas);
Roof	0.25	0.12 (coal); 0.10 (gas)	0.13 (coal); 0.15 (gas)	52% (coal); 60% (gas);

Table 38: The comparison of nZEB global cost solutions (according to macroeconomic ME and financial F approach) compared to basic variant (current requirements) - gas

		en_1	en_4 + w_2 + mv	en_4 + w_2 + mv + s	en_5 + w_2 + mv	en_5 + w_2 + mv + s
EP	[kWh/(m² a)]	124	67	58	62	52
2%/3% F	[€/m²]	0	-26	-11	-23	-11
2%/3% ME	[€/m²]	0	-33	-18	-31	-19
6%/5% F	[€/m²]	0	-55	-47	-57	-53
6%/5% ME	[€/m²]	0	-60	-52	-62	-58
6%/3% F	[€/m²]	0	-90	-84	-97	-98
6%/3% ME	[€/m²]	0	-96	-91	-104	-105

When gas was chosen as energy carrier, all considered packages were more profitable compared to the basic variant. The macroeconomic approach had no influence on the sequence of packages.

Table 39: nZEB global cost solutions (according to macroeconomic ME and financial F approach) compared to basic variant (current requirements) - coal

		en_1	en_4 + w_2 + mv	en_4 + w_2 + mv + s	en_5 + w_2 + mv	en_5 + w_2 + mv + s
EP	[kWh/(m² a)]	143	74	65	67	54
2%/3% F	[€/m²]	0	25	46	33	55
2%/3% ME	[€/m²]	0	17	38	24	46
6%/5% F	[€/m²]	0	12	29	18	35
6%/5% ME	[€/m²]	0	7	24	12	28
6%/3% F	[€/m²]	0	3	21	6	23
6%/3% ME	[€/m²]	0	-5	13	-2	14

When coal was chosen as an energy carrier, only two considered packages appeared as profitable within basic (6%/3%) energy price development scenarios, compared to the basic variant. The macroeconomic approach had no influence on the sequence of packages.

Discount rate variation

A sensitivity analysis was performed with a 5% discount rate and 2% energy price increase from the financial perspective. The results of the sensitivity analysis in terms of cost-optimal levels and the additional costs of energy performance standards revealed that there is a small difference between optimal packages in the range of particular energy carrier compared to the basic scenario. Even assuming a rather high (5%) discount rate, which caused the decrease of real energy prices, there is still a gap between current requirements and optimal packages.

Energy price development variation

Energy price development scenarios (2% or 6%) have the biggest influence on the global cost, but compared to different discount rate calculations they have a lower influence on the results concerning the optimal set of measures.

7. CONCLUSIONS AND FINAL RECOMMENDATIONS

The cost-optimal calculation undertaken for the three countries led to relevant recommendations concerning the main implementation steps and the selection of most influential factors. A summary of findings and results is presented in the following paragraphs.

7.1. Cost-optimal levels in the cost-optimal calculation for Austria, Germany and Poland

The cost-optimal sensitivity analysis for multi-family buildings connected to district heating in **Austria** identified a gap between actual and cost-optimal energy performance levels. From the financial perspective, and if the actual heating source (i.e. district heating) remains unchanged, the difference between actual and cost-optimal energy performance is 10.5% to 14.5%, according to different assumptions on input factors.

However, for packages of measures assuming other heating systems than the actual heating source (i.e. including biomass heating and solar systems and also ventilation), the gap between actual and cost-optimal energy performance increases to 15.4-21.6%.

Among the same packages of measures, the cost-optimal points move towards more ambitious levels, if one or more of the following conditions are met:

- Lower discount rate (i.e. from 3% to 1%),
- Higher energy prices development (i.e. from 2.8% to 4%),
- Reduction of investment costs between variants (based on regional cost differences/improved learning curve).

The calculations from private and macroeconomic perspectives lead to the same cost-optimal point, yet to lower global costs.

The cost-optimal calculation for **Germany** reveals that, from a financial perspective, the calculated cost-optimal primary energy values of new buildings are approximately 53 kWh/m^{2}a for the selected multi-family building (MFH), and 54 kWh/m^{2}a for the selected single-family building (SFH). The cost-optimal levels are not yet reached by the current requirements (EnEV 2009). The minimum energy performance requirements could be tightened by about 15 % to achieve cost-optimal levels and by about 25 % to achieve the same global costs as the EnEV 2009. The calculations from a macroeconomic perspective (without VAT and with cost of GHG emissions) show that the cost-optimal levels do not change compared to the private economic calculation. Only the additional costs of advanced energy performance standards decrease compared to EnEV 2009.

However, this gap will be closed by an EnEV recast drafted by the German government, and the maximum primary energy demand will be lowered in two steps, each by 12.5%.

Due to the flexibility when selecting certain factors (e.g. reference buildings, optional discount rates, selection of variants) a great number of cost-optimal levels or cost-optimal ranges occur. This appears to be a big challenge in implementing the cost-optimal methodology.

The calculation for Germany showed that lower discount rates and higher energy price development lead to lower cost-optimal primary energy values. Therefore, the gap with current requirements becomes bigger and the additional costs of higher energy performance standards decrease compared to EnEV 09.

The cost-optimal calculation for **Poland** revealed that there is a very big gap between current requirements and achieved results. Differences appear especially concerning the thermal resistance of the external envelope (e.g. required 0.3 U value for external walls versus 0.18 or 0.15 respectively for coal and gas as energy carriers). The use of a mechanical ventilation system with heat recovery, and of solar collectors, proved unprofitable in the case of coal as energy carrier. Despite the bigger differences in global costs between assumed packages and the basic variant at the macroeconomic approach, the calculations from the financial perspective led to the same cost-optimal packages.

In addition, calculations for different locations in Poland revealed a strong influence of the location on primary energy demand. The influence of the location on cost–optimality was not observed. These remarks can also be very helpful during the process of establishing requirements related to the energy efficiency of buildings.

7.2. Reference buildings

The accurate selection of reference buildings is a prerequisite to reach realistic results of the cost-optimal calculations.

Reference buildings selected for the cost-optimal calculation have to be representative of the existing building stock and the new buildings in each country. If the building stock and current trends in construction are wide, it is recommended to define enough reference buildings in order to represent the reality as faithfully as possible.

For the existing building stock, reference buildings should be defined based on the characteristics of the buildings and the analyses' purpose they aim to meet. Due to the limited statistical knowledge about the building stock, the choice of reference buildings becomes arbitrary; picking reference buildings might be a source of deviation and inconsistency in the cost-optimum comparison and thus, it is important to minimize the errors by an appropriate selection. Consequently, it is strongly recommended to have a close consultation with architects but also with contractors, in order to define reference buildings with simple and common geometries, realistic and easy to be reproduced in practice. Moreover, if possible, it is useful to design reference buildings based on plans of actually built houses, with simplifications or adaptations where necessary.

If the definition of new reference buildings is based on improved geometries and favourable orientations, it is recommended to also set appropriate conditions at the construction market and urban planning levels in order to realise the assumptions from the cost-optimal calculations.

If reference buildings are not properly selected in order to be reproducible in practice, they may lead to false results.

7.3. Packages of measures selection

The selection of the sets of measures significantly influences the results of the cost-optimal calculation on both energy performance and global costs. Therefore, particular attention should be paid when choosing appropriate packages of measures, including enough examples.

Test runs performed for the Commission revealed that the number of calculated packages of measures should certainly not be lower than ten in addition to the reference case. This will ensure that it is possible

to identify a line that represents the cost-curve and thus, reveals the optimum.
The calculation examples presented in this study suggest that a good approach to select packages is to define variants of thermal quality of the envelope and technical systems (e.g. heating, ventilation and cooling equipment), as well as to undertake the cost-optimal calculation for packages of measures based on these variants' combinations. Nevertheless, the combinations of thermal performance and equipment variants have to lead to realistic and complete packages. The reference package should reflect the existing requirements from building codes, as a benchmark for the energy and cost calculations.

In addition, the variants selected for the building equipment have to be in line with the existing situation, local renewable resources and complementary policies and strategies (e.g. urban or regional sustainable development policies).

When defining packages of measures, it is indicated to elaborate them as much as possible based on well-established official or voluntary building standards, such as those requested by on-going support programs (e.g. KfW standards are used in the German country report) or internationally accepted ones (e.g. Passive House).

Member States should apply and continuously use the cost-optimal methodology from now and onwards, and have to repeat it at least every 5 years. Moreover, the cost-optimal methodology has to be aligned to the long-term targets and goals, such as the introduction of nZEB by 2020, and the 2050 decarbonisation goals.

Therefore, it is recommended to include ambitious (as well as very ambitious) measures among selected packages in order to identify the remaining performance and financial gaps and to use accordingly these results to shape further policies and market support programs. Ambitious low-energy building standards should also be considered in order to have a timely evaluation of costs for the introduction of nearly Zero-Energy Buildings.

Preparing a wide and detailed selection of packages of measures from the beginning may avoid repeating the work at a later reapplication of the cost-optimal calculation. However, the investment costs for materials and equipment included in the packages of measures have to be re-evaluated at any further repetition of the cost-optimal calculation to ensure accuracy. It is important to track the cost evolution of the main building materials and equipment. Finally, it will be possible to use this historical database to track the market and to adjust support policies and strategies depending on its evolution.

7.4. Methodology and framework conditions

The energy performance of buildings has to be calculated in terms of primary energy, including energy use for heating, cooling, ventilation, domestic hot water, auxiliary services of the building and non-residential building lighting.

The basis of the cost-optimum analysis is the energy balance calculation according to the national methodologies, and it should also consider the European standards developed to support EPBD implementation. This calculation is based on standard assumptions of climatic conditions and user behaviour. These boundary conditions are not necessarily identical for typical or average values of the country. The national calculation methodologies have to be harmonized with the EPBD standards, as recommended by the Guidelines for the Cost-Optimal Regulation. Therefore, the global cost calculation method of the European Standards EN 15459 (Energy performance of buildings – economic evaluation procedure for energy systems in buildings) can be used to assess the financial performance of the chosen combinations of packages of measures. This method results in a discounted value of all costs during a defined calculation period.

As recommended by the *Cost-Optimal Regulation Guidelines* (EC, 2012b), the calculation of the building energy performance should consider the following:

- Thermal and electrical energy from renewables generated and used onsite have to be subtracted for the calculation of the building's net energy needs.
- The energy generated onsite and exported to the market has to be calculated and deducted from primary energy associated with the energy delivered to the building.
- The calculation of energy uses has to take into account the characteristics of generation, distribution, emission and control systems.

According to EN ISO 13790, the main calculation method to assess energy needs for heating and cooling has to be based on the energy balance of the building and its technical systems.

The packages of measures have to be compared with all building requirements in place in the country, including those for elements (U-values), technical system performance and for primary energy and renewable energy share.

As it is shown in the German country report, some of the calculated packages fulfil the condition of maximum U-values for building elements but fail to comply with the energy performance requirement for the whole building as requested by EnEV2009. Moreover, the renewable energy Ordinance EEWärmeG will introduce additional requirements to have renewable energy generation in new buildings or, alternatively, the primary energy limitation strengthened by 15%. The consideration of all existing requirements for buildings may introduce new limitations that have to be considered when evaluating the calculation results. Otherwise, it is possible to reach false cost-optimal results, which only partially respect the existing building codes.

Climate conditions also have to be taken into account, while it is recommended to do the cost-optimal calculation by considering all climatic zones across the country. The same package of measures may lead to different energy performances according to local climate conditions.

Conversion factors to evaluate the primary energy may also have an important influence on the cost-optimal calculation. Therefore, they have to be as accurate as possible and periodically adjusted to reflect the reality. If there are clear commitments and measures to gradually improve/reduce primary energy conversion factors (e.g. such as in Denmark), it is recommended to consider them as well.

The *Cost-Optimal Regulation Guidelines* recommend using the values from Annex A to EN 15459 on economic data for building elements when defining the estimated economic lifetime for building elements. The longer the lifetime of an element, the more marginal the influence on the disposal costs. It is unanimously agreed that the standard lifetime for thermal insulation measures are around 50 years, and 30-35 years for windows. For technical systems, there is however a wide variation from 15 to 35 years. Therefore, over a 30-year period, only the replacement costs of building equipment (e.g. HVAC plant) have a relevant influence on the cost-optimal calculation for new buildings. For the same reasons, the influence of disposal costs is also marginal for new buildings.

Overall, the integration of the cost-optimal methodology in a dedicated software program is a prerequisite in order to reduce the complexity of the methodology. Furthermore, once the methodology is settled, it is very important to constantly guarantee a high quality of input data to ensure a reliable result.

7.5. Costs of materials, work and equipment

Costs of workmanship, materials and equipment as well as the relevant input data influence strongly the cost-optimal calculation and the evaluation accuracy.

Nevertheless, costs accurate information seems to be scarce and not consistently collected in the European Member States.

In the country reports presented in this study, varied sources were used as well as market analysis with the support of industry associations. Overall, the study revealed the need to build official, credible and periodically updated cost databases at Member State level. The costs data collection should include all relevant stakeholders involved in the design and construction of buildings, (i.e. architects, associations of builders, of supply chain industry for materials and equipment) and should include surveys through retail outlets and distribution chains.

Furthermore, investment costs of energy saving measures for new buildings are not readily available among Member States, while there is no clear evidence of best practices for systematic collection of investment costs data.

An alternative method to determine the costs of different energy performance standards is to organise a broad market research exercise. The problem is that the energy quality of a building correlates also with other building features and there are still assumptions that need to be made. For example, it may be the case that energy efficient buildings like passive houses are currently constructed mainly by financially strong owners. The incremental insulation costs could only be determined if the other price determining features were equally increased. Indeed, there are no such comprehensive surveys available. In addition, it would also be necessary to cover a large number of buildings in order to gain enough accuracy.

In order to give credibility to the costs assumptions, but also to have a continuous adjustment process for costs data, publicly available databases should be developed and open to public scrutiny, debate and improvements. Eventually, the cost databases may be integrated as an activity of national statistical institutes and as part of a wider collection of building data. Overall, it is important to create them as a tool for the setting of building related policies. Otherwise, there is a risk of turning them into a theoretical exercise which, in that case, would negatively impact the accuracy of information.

Costs data collection is not only useful for the implementation of the cost-optimal methodology, but for defining building policies. Such policies are, for instance, the *Energy Efficiency Directive* (EC, 2012c) and its requirements for the elaboration of long-term renovation plans or potential complementary support policies fostering market transformation. Additional examples are public-private partnerships or voluntary agreements for cost/price roadmaps for efficient and renewable materials and equipment.

7.6. Discount rates and energy prices development

Discount rates influence the global costs and, as it was shown here (cf. Austria), a variation of more than 2% points may slightly shift the cost-optimal point in terms of building energy performance.

In Annex 1 (cost-optimal methodology framework) of the Cost-Optimality Delegated Regulation, it is set that Member States 'have to determine the discount rate to be used in the macroeconomic calculation after having performed a sensitivity analysis on at least two different rates, one of which shall be 3 % expressed in real terms'.

However, in the *Guidelines* accompanying the *Regulation* (chapter 6.4: discount rate), it is mentioned that 'the discount rate used in the macroeconomic and financial calculation is to be established by the Member State after performing a sensitivity analysis on at least two rates for each calculation. The sensitivity analysis for the macroeconomic calculation shall use one rate of 3% expressed in real terms[21]. Nevertheless, it is mentioned in the *Guidelines* that a higher discount rate will reflect a more commercial, short term approach, while the use of a lower discount rate (typically between 2% and 4% real) will better reflect the lifetime benefits for the building occupants.

While slightly confusing, above requirements indicate that, at least at a macroeconomic level, the cost-optimal calculations should be performed using a discount rate in the range of 2% to 4%, and 3% should be one of the considered discount rates.

Indeed, the discount rates have to reflect the actual capital costs for long-term mortgages or the expected minimum return on investment in case of self-financing. Usually, in macroeconomic calculations, the discount rate is considered slightly higher than the mortgage or interest rates, by adding a safety margin on top of these.

The safety margin reflects a potential postponement of an investment, if the analysis indicates that it may be better to wait for more favourable conditions. A good example is the case of an investment in a new power plant, because the consumption trends indicate a future need exceeding the actual installed capacity. Therefore, to estimate the investment profitability, it is necessary to analyse when this is appropriate to build it and what technology to use. This assessment may indicate that it is more profitable to invest a while later, but to use more efficient technology which is costly at the moment but has a tendency to become cheaper in a few years' time. Consequently, in the net present value calculations of macroeconomic analysis, a safety margin is added to the discount rate in order to include the investment option.

However, in case of building investments, in new construction or in renovation of existing buildings, there is no point to consider a later better investment to improve the energy performance. More specifically, from the investment point of view, an investment postponement will be a missed opportunity to maximize the benefits at the moment of the construction or during stringent renovation activities. A later intervention to improve the building's energy performance will certainly increase the investment costs. Therefore, the safety margin is meaningless in this specific case and should not be added to the discount rate. Moreover, when analysing an investment in the energy performance of buildings, the discount rate may be even lower than the long-term mortgages in order to reflect and reward an early and more profitable investment at the time of the imminent building construction or renovation.

In the German case, inflation-adjusted discount rates of about 3 % (real) are often used to assess the profitability of energy saving measures in existing and new residential buildings. The same applies to Austria, where a 2%-3% discount rate reflects the current interest rates for long-term mortgage secured loans, and has to be regarded as realistic. Overall, in EU countries with low risk of investment (similar to Austria and Germany), a 2%-3% discount rate seems to be realistic for both a private and a macroeconomic perspective. A better integration of benefits at the macroeconomic level may indicate the use of an even lower discount rate towards 1%.

If interest rates for long-term mortgages decrease (as for EU countries with different risk investment profiles such as Poland), the consideration of a 3% discount rate seems realistic from a macroeconomic perspective.

Nevertheless, it is important to highlight that the global costs resulting from the cost-optimal calculation will be higher when lower discount rates are applied, since future costs (including energy costs) are discounted at a lower rate.

[21] This is in line with the current Commission's 2009 Impact Assessment guidelines, which suggests 4 % as societal discount rate, corresponding to the average real yield on longer-term government debt in the EU over a period since the early 1980s.

Furthermore, the energy price development has an influence on the global cost calculation. Future energy costs per single time period always increase if the assumed energy price development in real terms (inflation adjusted) has a positive annual increase.

The variation of energy price development in conjunction with the variation of the discount rate has a more significant influence on the cost-optimal calculation. The Germany cost-calculations revealed a few interesting conclusions concerning the effects of these variations:

- The net present value of energy costs in every single future time period increases more slowly than the energy costs today (period 0), if the discount rate is higher than the assumed energy price development (e.g. discount rate 3 %; energy price development 1 %).
- The net present value of energy costs in every single future time period increases faster than the energy costs today (period 0) if the discount rate is lower than the assumed energy price development (e.g. discount rate 1 %; energy price development 3 %).

As indicated by the *Cost-Optimal Regulation* (Annex 2), Member States may consider the energy and fuel prices development trends as provided by the EU Commission (EC, 2009)[22] for their calculation. The latest update suggests a 2.8 % annual increase in gas prices, a 2.8 % annual increase in oil prices and a 2 % annual increase in coal prices. However, these trends are at the EU level and are based on a full implementation of the actual EU policies. At national and regional levels, the energy prices vary largely, which also influences future development.

Germany is a particular case with a current high electricity price that includes several components such as the support of renewable energies. Therefore, the price development assumed in national strategies is lower than the one recommended by the *Cost-Optimal Regulation*. However, the energy prices development is higher in other countries, based on historical data and national forecasts. For instance, in Austria, the energy prices evolution has been around 3.5%/year over the last decade. In Poland, the energy prices development assumed in national debates is even higher, due to the actual status. Overall, there are wide-ranging national or regional incentives and subsidies, introducing additional volatility and unpredictability at consumer prices (private perspective) on short and medium term.

Overall, it is relevant to consider also a higher energy price development in the cost-optimal calculation, which will probably be around 4 to 6%, depending on the country specific situation.

7.7.Cost-optimality, nearly Zero-Energy Buildings and long-term climate goals

By including ambitious packages of measures at very low energy-consumption levels in the cost-optimal calculation, it is possible to estimate the global cost impact of potential nZEB definitions. In addition to the requirement of preparing nZEB definitions, the EPBD asks Member States to present an implementation plan by 2020, including an interim target by 2015. Therefore, the results of cost-optimality could facilitate the definition of this interim nZEB target and could set a realistic and smoother trajectory of the buildings' requirements from the actual status towards nZEB levels by 2020.

In addition, the cost-optimal calculation at macroeconomic/societal perspective should consider the CO_2 emissions associated with the energy performance of simulated packages of measures, for the macroeconomic perspective. It becomes, therefore, possible to also estimate the associated CO_2 emissions of potential nZEB definitions.

Overall, the cost-optimal calculation may be very useful for estimating the financial, energy and environmental gaps between cost-optimal and nZEB levels, as well as to accordingly take appropriate measures and implement policies to minimize them.

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[22] The energy prices development are developed by using the PRIMES model and are available at : http://ec.europa.eu/energy/observatory/trends_2030/index_en.htm

As many other Member States, Austria, Germany and Poland have not yet announced official nZEB definitions and implementation plans. However, within the cost-optimal calculation performed in this study, packages of measures leading to very low-energy buildings have been taken into consideration.

For **Germany,** it has been assumed that the future nZEB definition will be close to the standard 'KfW Effizienzhaus 40'[23], which is the most ambitious level of the federal grant programme for new buildings. To fill the gap between the current requirements of EnEV 2009 and the nZEB level, it is recommended to tighten gradually the requirements. Therefore, the cost-optimal calculation for Germany included 'KfW Effizienzhaus 40' among a few other packages of measures at very low-energy levels.

Compared to typical construction costs for new buildings in Germany (1300 €/m^2), the additional global costs for the most cost-effective standards towards nZEB range between 2 and 8 %. These percentages are in a similar range with "typical fluctuations" of construction costs.

The CO_2 emissions associated to packages of measures defined at low-energy levels are in the range of 4.2 to 9.5 kg/m^2/yr for both SFH and MFH, according to the heating variants included in the packages. However, to be in line with the long-term climate goals, the associated CO_2 emissions of a future nZEB definition have to be below 3kg/m^2/yr, as it has been suggested in a previous BPIE study (BPIE, 2011).

The cost-optimal calculations for **Austria** also included several packages of measures at very low-energy levels, with primary energy demand between 30-50kWh/m^2/yr.

Compared to typical rent levels in multi-family houses (7 to 10 €/m^2 on average depending on the sector and region) and the levels of operating cost (0.50 to 1.50 €/m^2 except energy), the global cost differences between actual building requirement standards and standards that are (close to) nZEB levels are rather negligible. They do not exceed 0.15 €/m^2 and many of the highly efficient nZEB-variants are closer to the cost-optimum.

Among the packages of measures at low-energy levels, some have significantly low carbon emissions or even negative CO_2 balance due to the overcapacity of renewable energy generation.

The cost-optimal calculations for **Poland** also included several packages of measures at very low-energy levels, with primary energy demand between 52 and 74 kWh/m^2/yr.

The packages comprise several improved thermal envelope measures combined with two heating options on coal and gas (main heating carriers nowadays in Poland). When coal is considered for heating, there are only two cost-effective packages, both at a macroeconomic and financial calculation. However, when gas is considered as energy carrier for heating, all packages of measures are cost effective.

Nevertheless, the associated CO_2 emissions of the packages of measures based on gas and coal heating solutions are in between 9.2 and 13.7 kgCO_2/m^2/yr. Therefore, in the light of the upcoming implementation of nZEB in Poland, the consideration of renewable energy heating solutions is recommended to reduce the environmental impact of the energy use in buildings.

[23] "Efficiency Building 40" has a primary energy demand at 40% of the actual requirements (EnEV2009)

8. SUMMARY OF FINDINGS AND FINAL REMARKS

In chapter 7, we explained the influence of several factors on the results of cost-optimal calculation. In addition, we showed the added value of using cost-optimal calculation to evaluate environmental and financial gaps between cost-optimal and nZEB levels.

Please find overleaf a short summary of the main recommendations and findings for the cost-optimality methodology.

Reference buildings	• Have to **be representative of the existing building stock** and **new buildings** in each country; • With **simple geometries;** • **Reproducible** in practice;
Selection of packages of measures	• Number of calculated packages have to be **at least 10** in addition to the reference case, which reflects actual regulations; • Should be **based on existing or planned national standards** or/and on widely accepted ones; • **Very ambitious packages** of measures should also be considered to provide an estimation of the financial and environmental implications of upcoming **nZEB** requirements;
Methodology and framework conditions	• Calculation based on **primary energy;** • Including energy use for: heating, cooling, ventilation, domestic hot water, auxiliary services of the building and non-residential building lighting; • Harmonized with the **European Standards;** • Comparison of packages of measures with all building requirements in place in the country; • **Accurate conversion factors** and periodically updated;
Costs of materials, work and equipment	• **Lack of accurate information** of the costs in Member States; • Scarce and not consistently collected data; • **Databases** should be developed and **open to periodical scrutiny** of main stakeholders;
Discount rates and energy prices development	• Discount rates have to reflect the actual costs of capital for long-term mortgages or the expected minimum return on investment in case of self-financing; • In the case of buildings, **the discount rate should be even lower than long-term mortgages** in order **to reflect the profitability of the investment** in energy savings measures at the time of the imminent construction or renovation of building; • The energy prices development as well the relation with discount rate influence the global costs calculation and may slightly shift the cost-optimal point;
Cost-optimality, nearly Zero-Energy Buildings and long-term climate goals	• Cost-optimality: a useful tool to estimate the **financial, energy and environmental gaps** between cost-optimal and nZEB levels • And for taking appropriate and implementing policies to bridge the gap.

Overall, the implementation of the cost-optimal methodology in the EU countries should lead to more consistent and coherent building policies across Europe. The cost-optimal methodology will introduce all over EU the lifetime assessment of the building costs (vs. only investment costs) as a tool to shape the energy requirements for new and existing buildings. Thus, the narrow evaluation at investment costs levels will be replaced by a more consistent and sustainable assessment of all building related expenses and savings.

This new approach offers at the same time a new platform to design long-term building strategies and policies, to eliminate the existing market barriers, change the actual way of thinking only at the upfront capital, for a better integration of buildings related climate and energy policies.

However, all these potential benefits may be endangered if the cost-optimal process will not be properly implemented. To avoid this and in order to stimulate the whole process, there is a need for more guidance, best practices exchange between MS representatives and experts and, last but not least, awareness rising among stakeholders and citizens concerning the benefits.

REFERENCES

BMVBS, 2010. BMVBS (Hrsg.): Externe Kosten im Hochbau, BMVBS-Online-Publikation, Nr. 17/2010

BMVBS, 2012. BMVBS (Hrsg.), Untersuchung zur weiteren Verschärfung der energetischen Anforderungen an Gebäude mit der EnEV 2012 – Anforderungsmethodik, Regelwerk und Wirtschaftlichkeit, BMVBS-Online-Publikation 05/2012.

BPIE, 2010. "Cost-optimality. Discussing methodologies and challenges within the recast Energy performance of Buildings Directive". Available at: http://www.bpie.eu/documents/BPIE/BPIE_costoptimality_publication2010.pdf

BPIE, 2011. "Principles for nearly-Zero Energy Buildings. Paving the way for effective implementation of policy requirements". Available at: http://www.bpie.eu/documents/BPIE/publications/HR_nZEB%20study.pdf

Brown, Matysiak, 2000. "Real estate investment: A capital market approach", London/ Singapore 2000

CEN, 2008. "Explanation of the general relationship between various European standards and the Energy Performance of Buildings Directive (EPBD) - Umbrella Document."

COM, 2011a. 112 final. "A Roadmap for moving to a competitive low carbon economy in 2050". Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52011DC0112:EN:NOT

COM, 2011b. 885 final. "Energy Roadmap 2050". Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52011DC0885:EN:NOT

COM, 2011c. 571 final. "Roadmap for a Resource Efficient Europe". Available at: http://ec.europa.eu/environment/resource_efficiency/pdf/com2011_571.pdf

EC, 2009. European Commission. "EU energy trends to 2030. Update 2009. Available at: http://ec.europa.eu/energy/observatory/trends_2030/index_en.htm

EC, 2010. European Commission. "EU energy trends to 2030 – update 2009". European Commission

EC, 2012a. European Commission. "Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements". Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:081:0018:0036:EN:PDF

EC, 2012b. European Commission. "Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 supplementing Directive 2010/31/EU by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements (2012/C 115/01)". Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2012:115:0001:0028:EN:PDF

EC, 2012C. European Commission. "Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:FULL:EN:PDF

Eceee, 2011. "Cost-optimal building performance requirements. Calculation methodology for reporting on national energy performance requirements on the basis of cost-optimality within the framework of the EPBD". Available at: http://www.eceee.org/buildings/cost_optimality/cost_optimality-eceeereport.pdf

EPBD, 2010/31/EU. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

Hinz, E., 2010. Untersuchung zur weiteren Verschärfung der energetischen Anforderungen an Wohngebäude mit der EnEV 2012. Teil 1 - Kosten energierelevanter Bau- und Anlagenteile in der energetischen Modernisierung von Altbauten; im Auftrag des BBSR; IWU; Darmstadt 2010

Hofer, G., Herzog, B., 2011. Planungsunterstützende Lebenszykluskostenanalyse für nachhaltige Gebäude. Available at: http://www.e-sieben.at/de/download/Hofer_Herzog_Planungsunterstttzende_Lebenszykluskostenanalyse.pdf

IWU, 2009. "Kumulierter Energieaufwand und CO2-Emissionsfaktoren verschiedener Energieträger und –versorgungen". Available at: http://www.iwu.de/fileadmin/user_upload/dateien/energie/werkzeuge/kea.pdf

IWU, 2012. "Evaluation and Further Development of EnEV 2009: Study about the Economic Framework Conditions in Housing", Study commissioned by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BMVBS). Diefenbach, N., Enseling, A., Hinz, E., Loga, T.: Evaluierung und Fortentwicklung der EnEV 2009: Untersuchung zu ökonomischen Rahmenbedingungen im Wohnungsbau; im Auftrag des BBSR; IWU / BBSR 2012.

Schöberl, H. 2011. Reduktion der Wartungskosten von Lüftungsanlagen in Plus-Energiehäusern, Projektbericht im Rahmen der Programmlinie Haus der Zukunft, Wien, Oktober 2011

Schöberl, H., Lang, C., Handler, S., 2012. Ermittlung und Evaluierung der baulichen Mehrkosten von Passivhausprojekten, Projektbericht im Rahmen der Programmlinie Haus der Zukunft, Wien, August 2012

ZUB, 2010. Klauß, S., Maas, A. Entwicklung einer Datenbank mit Modellgebäuden für energiebezogene Untersuchungen, insbesondere der Wirtschaftlichkeit; Studie durchgeführt im Auftrag des BMVBS sowie des BBSR; Zentrum für Umweltbewusstes Bauen e.V., Kassel 2010. Available at: http://www.irbnet.de/daten/baufo/20118035234/Endbericht.pdf

ANNEX 1

SHORT GUIDANCE ON COST-OPTIMALITY METHODOLOGY

Cost-optimum, *Delegated Regulations*
The *Regulations* consist of 15 Preambles, 7 Articles, and 3 non-binding Annexes. The preambles elaborate on some of the terms and regulations given in the articles. Below are some highlights.

Article 2 - Definitions
Article 2 gives all relevant definitions needed to make the cost-optimum calculations and analyses.
Among them is the definition (11) of reference buildings, stating that a "Reference building means a hypothetical or real reference building that represents the typical building geometry and systems, typical energy performance for both building envelope and systems, typical functionality and typical cost structure in the Member State and is representative of climatic conditions and geographic location".
Article 2(19) describes the meaning of packages of energy-saving measures: "Package means a set of energy efficiency measures and/or measures based on renewable energy sources applied to a reference building". Furthermore, preamble 13 states that "The cost-optimal methodology is technologically neutral and does not favour one technological solution over another. It ensures a competition of measures/ packages/ variants over the estimated lifetime of a building or building element". Technological neutrality is ensured by making different technologies compete by their cost and their ability to provide energy efficiency for the specific calculation case.

Article 3 - Comparative methodology framework
Article 3 sets the overall lines for the cost-optimal framework. It describes what is defined and stated by the EC and what MS have to define themselves.

The framework prescribes calculation of cost-optimal levels from both macroeconomic and financial viewpoints, but leaves it up to the MS to determine which of these calculations is to become the national benchmark against which national minimum energy performance requirements will be assessed.
In addition to this, MS must complement the comparative methodology by determining:

a) The estimated economic lifecycle of a building and/or building element;
b) The discount rate;
c) The costs for energy carriers, products, systems, maintenance cost, operational costs and labour costs;
d) The primary energy factors;
e) The energy price developments to be assumed for all energy carriers taking into account the information in Annex II of the *Regulations*.

Member States must make an analysis to determine the sensitivity of the calculation outcomes to changes in the applied parameters. It should cover at least the impact of different energy price developments and the discount rates for the macroeconomic and financial calculations. Ideally this includes other parameters expected to have a significant impact on the outcome of the calculations such as price developments for other parameters.

Article 4 - Comparison with current minimum EP requirement
When the cost-optimum calculations for both a macroeconomic and a financial perspective are made, MS must decide which level to compare with the current minimum energy performance (EP) requirements. This comparison must be made for each relevant building category.

Article 5 - Review of the cost-optimum calculations
Before every update of MS national or regional EP requirements, a review of the cost-optimum calculations must be made. To be reviewed and updated mainly: the price developments for the input and cost data.

Article 6 – Reporting
Article 6 clearly states MS's responsibilities regarding reporting of the cost-optimum calculations, including what should be reported.
Not only the results of the calculations must be reported, but MS must also report all input data and assumptions used for the calculations and the results of those calculations. This report must include: applied primary energy conversion factors; results of the calculations at macroeconomic and financial level; sensitivity analysis; and assumed energy and carbon price developments.

Furthermore, MS are requested to compare the calculated cost-optimal level with their national or regional energy performance requirements. If the result of the comparison shows that the minimum energy performance requirements in force are significantly less energy efficient than the cost-optimal levels of minimum energy performance requirements, the report must include a justification for the difference. In this context, "significantly less" means that the current EP requirements are more than 15 % higher than the cost-optimal level. Then, a justification must be included in the reporting or a plan of how to reach 15 % of the cost-optimal level.

Annex 1 – Cost-optimal methodology framework
Annex 1 includes 6 sections, each dealing with different technical aspects of the calculation methodology:

- Establishment of reference buildings,
- Identification of energy efficiency measures,
- Calculation of the primary energy demand,
- Calculation of the global cost,
- Sensitivity analysis,
- Derivation of a cost-optimal level of EP for reference buildings.

<u>Selected highlights from Annex 1 to support the session discussion below.</u>

Annex 1.1 – Reference buildings
MS must establish reference buildings for the following building categories as a minimum:

1. Single-family buildings;
2. Blocks of flats and multifamily buildings;
3. Office buildings.

In addition to office buildings, MS must establish reference buildings for other non-residential building categories for which specific energy performance requirements exist.
To limit the administrative burden, it should be possible for MS to reduce the number of calculations by establishing reference buildings that are representative of more than one building category.
MS must also calculate cost-optimal levels for minimum performance requirements for building elements installed in existing buildings or must derive them from the calculations made at the buildings level.

Article 1.2 – Identification of energy efficiency measures
It is requested that MS identify measures/packages/variants using renewable energy for both new and existing buildings. Measures must also be compiled in such a way that they meet the minimum energy performance requirements for nearly Zero-Energy Buildings for new and possibly also existing buildings.

Indoor air quality and indoor comfort must be of high priority when calculating cost-optimal levels and, therefore, it is stated that energy efficiency measures must also be compatible with air quality and indoor comfort levels according to CEN standard 15251 on indoor air quality, or equivalent national standards. In cases where measures produce different comfort levels, this must be made transparent in the calculations.

Annex 1.4 – Calculation of global cost
The annex states that the global cost calculation should preferably be based on the net present value approach (EN15459) and include the cost categories: initial investment costs; running costs; energy costs (incl. energy price, capacity tariffs and grid tariffs); and disposal costs, if appropriate. For the calculation at the macroeconomic level, MS must in addition establish the cost category "Cost of greenhouse gas emissions".

Annex 2 – Information
Annex 2 contains global information about the estimated energy and carbon price development.

Annex 3 – Reporting template
Annex 3 contains a reporting template which can be used for reporting the input data and the result of the cost-optimum calculations and analyses. Table 7 is central in this template, which shows the comparison between the calculated cost-optimal level and the current national or regional energy performance requirements for all building categories.

Cost-optimum, Guidelines
The *Guidelines* follow the *Regulations* closely: a lot of the content and definitions are already given in the *Regulations*. The primary purpose of the *Guidelines* is to help with the practical implementation of the cost-optimum calculation and analyses in MS.

Establishment of reference buildings
There are two ways of defining reference buildings for the cost calculations, either by selecting a real example representing the most typical building in a specific category or by creating a 'virtual building' which includes the most commonly used materials and systems. No matter which approach MS select, it must, as much as possible, be based on statistical information on the building stock.

In order to reduce the administrative burden of performing cost-optimum calculations, this is possible to select building types as representative of other building types. It is however doubtful how MS can prove that an office building is representative e.g. of a hospital. This kind of approach needs to be tested, but it will probably be very difficult to verify that such a simplification is valid. If this approach is selected, it must be clarified in the first report to the Commission and can then be omitted in the next one.

Measures identification
Applying several variants (measures/packages) to several reference buildings can easily result in thousands of calculations. However, test runs performed for the Commission did reveal that the number of calculated variants should certainly not be lower than ten plus the reference case. This ensures that it is possible to identify a line that represents the cost-curve and thus reveals the optimum.

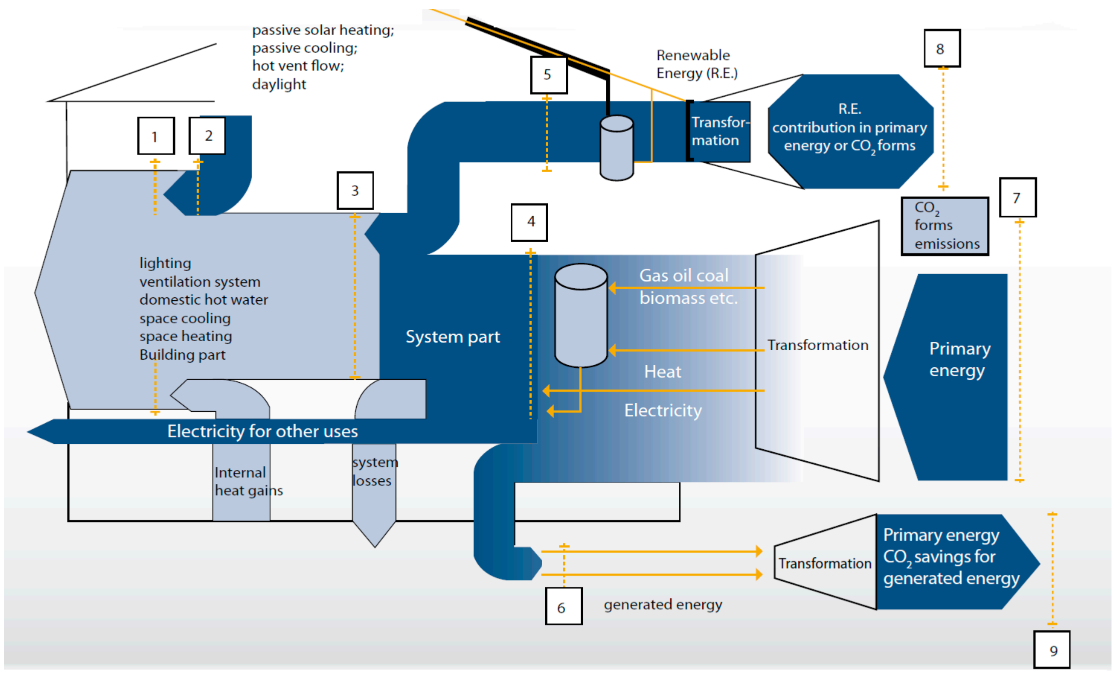
Stochastic methods for energy performance calculation can be used effectively, presenting the effects of particular measures and their combinations. From that, a limited number of combinations of the most promising measures can be derived. The number of full cost-optimum calculations can then be reduced to the most promising packages.

When performing cost-optimum calculations, MS should be aware that it is not necessarily helpful to produce a big amount of variants. Choosing selected packages from promising combinations may prove to be more efficient. It is thus a combination of doing enough calculations and not starting with measures less efficient than current requirements. Stochastic methods can be a strong tool to select the most promising packages.

Calculation of the primary energy demand
According to the *Regulations*, MS should use their national calculation methods for calculating building's Energy Performance (EP) and setting EP requirements to new and existing buildings. To take into consideration the EPBD, the MS national calculation procedure must take into account the energy flows and processes illustrated in the figure below.

Figure 1. Calculation scheme according to CEN/TR 15615 (umbrella document).

Source: Cost-optimality - Discussing methodology and challenges within the EPBD recast. Ecofys for BPIE 2010.



Global cost calculation

According to the Regulations and Guidelines, the global cost must be calculated according to EN15459 as:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \cdot R_d(i) \right) - V_{f,\tau}(j) \right]$$

Where

$C_g(t)$ Global costs referring to the starting year τ_0

C_I Initial investment costs

$C_{a,i}(j)$ Annual costs year i for energy-related component j (energy costs, operational costs, periodic or replacement costs, maintenance costs)

$R_d(i)$ Discount rate for year i (depending on interest rate)

$V_{f,\tau}(j)$ Final value of component j at the end of the calculation period (referred to the starting year τ_0). Here, the disposal cost (if applicable) can also be taken into account.

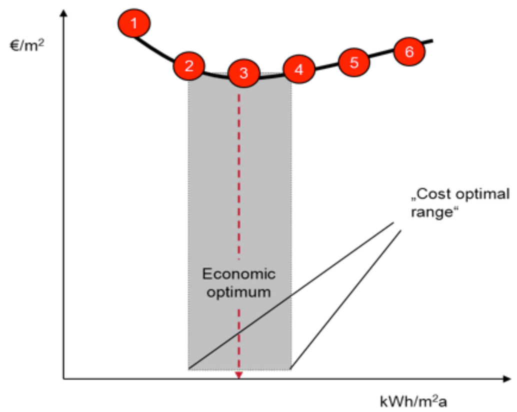
The *Guidelines* describe how to deal with residual value and serve as a guidance document to the *Regulations*. The cost-optimum calculations are based on a net present value calculation.

Derivation of cost-optimal level

Actually, the cost-optimum is rarely found as a single package of measures applied to a reference building, but rather as a set of more or less equally valid or cost-optimal solutions that can be considered as expanding a cost-optimal range.

Figure 2. Different variants on the cost-optimal curve and position of the cost-optimal range.

Source: Boermans, Bettgenhäuser et al., 2011: Cost-optimal building performance requirements - Calculation methodology to report on national energy performance requirements on the basis of cost-optimality within the framework of the EPBD, eceee.



When discussing cost-optimal levels and the effort to achieve energy savings, only the lower boundary of the cloud is interesting to identify the cost-optimal level. In case of a flat cost-curve, it was suggested to set the requirements in the lower (left) part of the calculated cost-optimal points. This will ensure that the most energy-efficient solution sets are selected. On the other hand, one should also try to avoid going too far on the left side of the curve, as cost-curves often show a tendency of a steep increase in costs when moving to the far left.

Sensitivity analysis

In the *Regulations* and *Guidelines*, MS are requested to carry out sensitivity analyses for the cost-optimal calculations with variations of energy prices as well as interest rate for both macroeconomic and financial cost calculations. However, other parameters affect the cost-optimum calculations and MS are therefore

encouraged to conduct more sensitivity analyses to see the effect of other variables.
Variations of energy prices are estimated by the EU, and the currently projected long-term price development is forecasted until 2030 to be:

- 2.8 % annual increase of gas prices
- 2.8 % annual increase of oil prices
- 2.0 % annual increase of coal prices

These trends may be extrapolated beyond 2030, at least until more long-term projections become available. Furthermore, the description of the estimated long-term development must be adjusted for electricity price developments, including tax.

ANNEX 2

REPORTING TABLES FOR ENERGY PERFORMANCE RELEVANT DATA

A. Case study Austria: Reporting table for energy performance relevant data

Reference Building			Quantity	Unit
Building	Model building		Residential building (MFH)	
	Description of the building		Reinforced concrete with external insulation, heating and hot water combined	
	Initial variant (V1)		Current Austrian building reg., net heat demand NHD = 16 x (1+3/lc)	
Calculation	Method and tool(s) for calculating the energy performance		ON-B 8110-6, ON-H 5056-5059, OIB guideline 6 Excel Tool (online available)	
	Primary energy conversion factors	Electricity	2.62	kWh/kWh
		Gas	1.17	kWh/kWh
		District heating	0.92	kWh/kWh
		District heating high efficient CHP	0.30	kWh/kWh
		Biomass (Pellets)	1.08	kWh/kWh
Climate condition	Location		Vienna	
	Heating degree-days		3.459	Kd
	Source of climatic dataset		Austrian standard for energy performance of buildings ON B 8110-5	
	Cooling Degree Days		No cooling	
	Terrain description		Urban area	
Building geometry	Length x Width x Height	external dimensions	12x32x18	m x m x m
	Number of floors		6 floors	
	Conditioned gross floor area (Reference Area)		2,304	m^2
	Surface to volume ratio (based on external dimensions)		0.34	m-1
	Compactness lc (reciprocal of surface to volume-ratio)		2.94	m
	Surface area	Facade North	576	m^2
		Facade East	216	m^2
		Facade South	576	m^2
		Facade West	216	m^2
		Flat roof	384	m^2
		Ground floor	384	m^2
	Window area		316.8	m^2
	Ratio of window area	North	36	%
		East	14	%
		South	36	%
		West	14	%
	Orientation		0	°

Reference Building			Quantity	Unit
Internal gains	Building use		Residential	
	Average thermal gain (sum of all sources)		3.75	W/m^2
Building elements	Average U-value of walls		0.27	$W/(m^2K)$
	Average U-value of roof		0.15	$W/(m^2K)$
	Average U-value of basement		0.30	$W/(m^2K)$
	Average U-value of windows		1.20	$W/(m^2K)$
	Thermal bridges	Additional losses related to the thermal envelope area	Simplified according to ON B 8110-6	
	Infiltration rate (air changes per hour)	Blower door: 50 Pa	3.0 (requirement for buildings without ventilation system)	h-1
Building systems	Efficiency of heating and DHW systems	fGEE ratio of end-energy-demand to end-energy-demand for reference building system	0.85	
	Efficiencies for each system are not obvious			
Building setpoints	Temperature setpoint		20	° C
Building energy need / use (related to gross floor area)	Net energy demand	Heating	32	$kWh/(m^2a)$
		DHW	13	$kWh/(m^2a)$
	Energy use generation and distribution		16	
	Energy use for auxiliary systems		1	$kWh/(m^2a)$
	End-energy-demand		62	
Energy consumption	Delivered energy for heating and DHW	Electricity	1	$kWh/(m^2a)$
		District heating	61	$kWh/(m^2a)$
Environmental assessment	Primary energy		58	$kWh/(m^2a)$
	Primary energy renewable		44	$kWh/(m^2a)$
	CO2 Emissions		4.76	kg/m^2a

B. Case Study Germany: Reporting table for energy performance relevant data

Reference Building			Quantity		Unit
Building	Model building		SFH semi-detached	MFH semi-detached	
	Variant		Requirements of EnEV 2009 and EEWärmeG; assuming condensing boilers + thermal solar systems		
Calculation	Method and tool(s)		EnEV 2009 / DIN V 4108-6 + DIN V 4701-10 calculation tool: EnEV-XL 4.0		
	Primary energy conversion factors		EnEV 2009 / DIN V 4108-6 + DIN V 4701-10 calculation tool: EnEV-XL 4.0		
			Natural gas: 1.1 Electricity: 2.6 Wood pellets: 0.2		
Climate condition	Location		Reference climate Germany (synthetical climate)		
	Heating degree-days		According to DIN V 4108-6 (base temperature 10°C): (10 °C - 3.3°C) · 185 d/a = 1240 Kd/a According to TABULA (base temperature 12°C, see www.building-typology.eu): (12 °C - 4.4°C) · 222 d/a = 1687 Kd/a		
	Source of climatic dataset		Reference climate Germany, according to DIN V 4108-6 Part D		
Reference area	Living space according to national housing regulations		139.0	473.0	m^2
	Reference area according to national asset rating method		187.5	591.4	m^2
Building geometry	Length x Width x Height		External dimensions: 7.5 x 11.4 x 9.7 (internal dimensions cannot be determined due to lack of plans)	External dimensions: 11.0 x 14.0 x 12.0 (internal dimensions cannot be determined due to lack of plans)	m x m x m
	Number of floors		1 complete storey + attic storey	4 complete storeys	
	Surface to volume ratio		0.59 (based on external dimensions)	0.42 (based on external dimensions)	m^2/m^3
	Ratio of window area over total building envelope	South	3.3%	0.0%	
		East	2.5%	7.0%	
		North	1.7%	0.0%	
		West	0.0%	8.5%	
	Orientation		0°	0°	

Reference Building			Quantity		Unit
Internal gains	Building use		Residential	Residential	W/m^2
	Average thermal gain		Sum of all sources: 5	Sum of all sources: 5	W/m^2
Building elements	Average U-value of walls		0.33	0.29	W/(m^{2}K)
	Average U-value of roof		0.31	0.26	W/(m^{2}K)
	Average U-value of basement		0.48	0.43	W/(m^{2}K)
	Average U-value of windows		1.30	1.30	W/(m^{2}K)
	Thermal bridges	Additional losses related to the thermal envelope area	0.02 (based on external dimensions)	based on external dimensions)	
	Infiltration rate (air changes per hour)	Blower door: 50 Pa	3.0 (requirement for buildings without ventilation system)	3.0 (requirement for buildings without ventilation system)	1/h
Building systems	Efficiencies of heating systems (related to net calorific value)	Generation	104.2%	102.2%	
		Distribution	2.1%	2.4%	
		Emission + control	1.4%	2.0%	
	Efficiencies of DHW systems (related to net calorific value)	Generation	89.1%	91.2%	
		Storage	12.6%	11.0%	
		Distribution	23.1%	40.3%	
Building energy need / use (related to living space)	Energy need	Heating	78	56	kWh/(m^{2}a)
		DHW	17	16	kWh/(m^{2}a)
	Energy use for auxiliary systems		5	3	kWh/(m^{2}a)
	Thermal energy from RES (thermal solar collector)		16	14	kWh/(m^{2}a)
	Delivered energy for heating and DHW	Electricity	0	0	kWh/(m^{2}a)
		Fossil fuel (natural gas)	74	43	kWh/(m^{2}a)
		Biomass (wood pellets)	0	0	kWh/(m^{2}a)
Environmental assessment	Primary energy		94	59	kWh/(m^{2}a)

C. Case study Poland: Reporting table for energy performance relevant data

Reference Building			Quantity	Unit	Description
Calculation	Method and tools	PN EN – ISO 13790 : 2009			

	Primary energy factor	coal: PEF = 1.1;
		w. pellets: PEF = 0.2;
		natural gas: PEF = 1.1;
		heating oil: PEF = 1.1;
		electricity: PEF = 3.0.
					Values of delivered to primary energy conversion factors (per energy carrier) used for the calculation

Climate condition	Location	Warszawa, Koszalin, Wrocław, Olsztyn, Suwalki			
	Heating degree – days			HDD	
	Cooling degree – days			HDD	
	Source of climatic dataset	http://www.transport.gov.pl/2-48203f1e24e2f-1787735-p_1.htm			EN ISO 15927:4
	Terrain description	Sub-urban area			
Building geometry	Length x Width x Height	12.6 x 11.09 x 8.23		m x m x m	
	Number of floors		2	-	
	S/V (surface – to - volume) ratio		0.8	m2/m3	
	Ratio of window area over total building envelope	South	1.66	%	
		East	1.46	%	
		North	0.89	%	
		West	1.27	%	
	Orientation				
Internal gains	Building utilization		single family house		
	Average thermal gain from occupants		3.5	W/m2	
	Specific electric power of the lighting system		-	W/m2	
	Specific electric power of electric equipment		-	W/m2	
Building elements	Average U – value of walls		0.30	W/(m2K)	
	Average U – value of roofs		0.25	W/(m2K)	
	Average U – value of basement		0.45	W/(m2K)	
	Average U – value of windows		1.5	W/(m2K)	
	Thermal bridges	Total length	187.4	M	
		Average linear thermal transmittance	0.117	W/(mK)	
	Thermal capacity per unit area	External walls	100000	J/(m2K)	
		Internal walls	100000	J/(m2K)	
		Slabs			
	Type of shading systems		no shading		
	Average g – value of	Glazing	0.67	-	
		Glazing + shading	0.67	-	
	Infiltration rate (air changes per hour)		2	1/h	Calculated for a pressure difference inside/outside of 50 Pa (blower door test)

Reference Building				Quantity	Unit	Description
Building systems	Ventilation system	Air changes per hour		0.42 (185 m3)	1/h	
		Heat recovery efficiency		0	%	
	Efficiencies of heating system	Generation		0.98	%	
		Distribution		0.98	%	
		Emission		1.0	%	
		Control		0.96	%	
	Efficiencies of cooling system	Generation		-	%	Not considered
		Distribution		-	%	Not considered
		Emission		-	%	Not considered
		Control		-	%	Not considered
	Efficiencies of DHW system	Generation		0.9	%	
		Distribution		0.9	%	
Building setpoints and schedules	Temperature setpoint	Winter		20	°C	
		Summer		-	°C	Not considered
	Humidity setpoint	Winter		-	%	Not considered
		Summer		-	%	Not considered
	Operation schedules and controls	Occupancy		Constant		
		Lighting				
		Appliances				
		Ventilation				
		Heating system				
		Cooling system				
Energy building need/use	Delivered energy for heating and DHW					
	Energy need for heating			15 054	kWh/a	
	Energy need for cooling			-	kWh/a	Not considered
	Energy need for DHW			2 409	kWh/a	
	Energy need for other (humidification, dehumidification)			-	kWh/a	Not considered
	Energy use for ventilation			-	kWh/a	Not considered
	Energy use for internal lighting			-	kWh/a	Not considered
	Energy use for other (appliances, external lighting, auxiliary systems, etc.)			-	kWh/a	Not considered
Energy generation at the building site	Thermal energy from RES (e.g. thermal solar collectors)			-	kWh/a	Energy from renewable sources (that are not depleted by extraction, such as solar energy, wind, water power, renewed biomass) or co-generation
	Electrical energy generated in the building and used onsite			-	kWh/a	
	Electrical energy generated in the building and exported to the market			-	kWh/a	
Energy consumption	Delivered energy	Electricity		-	kWh/a	
		Natural gas		19 374	kWh/a	
	Primary energy			21 312	kWh/a	

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